

NATIONAL SYNCHROTRON LIGHT SOURCE

VACUUM SYSTEM FOR NATIONAL SYNCHROTRON LIGHT SOURCE*

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I. Introduction

The National Synchrotron Light Source (NSLS), a 24 million dollar project under construction at Brookhaven National Laboratory (BNL), is a research facility dedicated to the production of synchrotron radiation. Synchrotron radiation is that radiation produced by the acceleration of charged particles at near the speed of light. This facility will provide a continuous spectrum of radiation from the vacuum ultraviolet to the hard X-ray range. The radiation will be highly intense, 100% polarized, extremely well collimated and will have a pulsed time structure. The radiation will be produced in two electron storage rings at energies of 700 MeV and 2.5 GeV respectively. A maximum of one ampere at 2 GeV, or one half ampere at 2.5 GeV, of electron beam will be stored.

Synchrotron radiation has applications in material studies, surface physics, solid state physics, chemistry, biology, and in new areas of technology such as X-ray lithography, now possible because of the unusual properties of this radiation.

Basic vacuum system parameters are listed in Table 1.

* Research supported by the Division of Basic Energy Sciences, Department of Energy, under Contract No. EY-76-C-02-0016.

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II. Problems of Synchrotron Radiation Vacuum Systems

From a vacuum standpoint, gas desorption due to synchrotron radiation is by far the most significant problem in this type of vacuum system. Power dissipation in the vacuum chamber walls is another, and localized heating due to higher mode RF losses is still another.

Synchrotron radiation is produced by accelerating electrons in a storage ring which results in a continuous spectrum of radiation. This radiation (synchrotron light) forms a very thin ribbon emanating from the electron beam which either terminates at the vacuum chamber wall or passes down the experimental beam lines to the experimental apparatus. At the chamber wall photoelectrons are produced which re-lease sorbed gas molecules. Gas is desorbed both when the photoelectron leaves the surface and again when it returns. The amount of gas desorbed in this manner exceeds the thermal gas load by a few decades and constitutes the main gas load in an electron storage ring.

In addition to the increased gas load, the radiation deposits energy in the chamber wall which must be removed to maintain a constant chamber temperature and to prevent melting. In the X-ray ring, a total of 252 kW is radiated, with a linear distribution of 48 W/cm, within a strip .033 cm high. This occurs along the wall of the vacuum chamber within a bending magnet. Cooling is via water channels in the vacuum chamber.

The cooling at beam ports is a more serious problem. At these locations, the photon beam is normal to the corner, formed by the beam pipe joining the vacuum chamber. This normal incident radiation results in a power loss of 425 W/cm at the corner.

The RF accelerating system (50 MHz) produces a bunched electron beam which can excite parasitic RF modes where the chamber cross-section changes, such as in bellows, joints, pump ports, etc. These beam energy

losses can cause localized heating of the vacuum hardware in these areas and careful consideration must be given to component design.

Finally, hydrocarbon contamination will seriously reduce the useful lifetime of the optical elements, such as mirrors and monochromators, and considering that the full compliment of experimental beam lines is forty four, efforts are being made to completely eliminate any oil pumps from the system.

III. Vacuum System Design

A vacuum system schematic is shown in Fig. 1. It consists of an electron linac, booster and two storage rings with a number of experimental beam lines on each storage ring.

1. Injection, Linac and Booster

The electrons are produced from a heated cathode and injected into a 100 MeV linac. The linac has a brazed copper vacuum system with all metal seals except for valve seats. The operating pressure of 10^{-5} Pa (10^{-7} Torr) is achieved with commercial sputter-ion pumps. A mild hot water bakeout is used to reduce the conditioning time.

The booster vacuum system consists of a stainless steel vacuum chamber with ceramic sections for the beam injection and ejection components. The stainless steel chamber will be quite thin (0.75 mm), to reduce eddy current losses, and will have external supports to prevent collapsing. The booster chamber cross-section is elliptical, 120 mm wide and 30 mm high. Sputter-ion pumps are planned to pump the system to it's operating pressure of 10^{-5} Pa (10^{-7} Torr). The vacuum chambers and components will be welded in place to form one continuous ring, thus eliminating flanges and reducing potential leaks.

The beam transport lines, from the linac to the booster, and from the booster to each storage ring, will be made from 60 mm diameter stainless steel tubing field welded in place. 60 liter/sec sputter-ion pumps will be used as required. Differential pumping will be necessary on the booster to storage ring transport lines to reduce the pressure from 10^{-5} Pa (10^{-7} Torr) to 10^{-8} Pa (10^{-10} Torr).

2. Storage Rings, VUV and X-Ray

To insure a useful beam life in excess of ten hours, a pressure of 10^{-8} Pa (10^{-10} Torr) is required (1,2). This is not difficult to achieve considering only thermal outgassing. However, as electrons are accelerated in the storage rings the synchrotron radiation-induced gas desorption far exceeds the thermal gas desorption and it becomes impossible to accelerate any more than a low intensity electron beam because of beam residual gas interactions. However, since the gas desorption rate is directly proportional to desorption coefficient η , the beam intensity could be increased if the coefficient η was lowered. This can be done by self-cleaning, bakeout or by an in-situ argon glow discharge.

Self-cleaning refers to using the electron beam itself to condition the vacuum chamber. This is a lengthy process that starts by first accelerating a low intensity beam in the storage ring, then conditioning to that intensity, followed by accelerating a slightly higher current and repeating the procedure until the desired beam current is reached. Calculations (1,3), as well as actual accelerator operation (4), have shown that this approach can take from a few weeks to a few months to reach full intensity, depending on the beam life and the desorption coefficients used in the computation.

Argon glow discharge conditioning is a much faster procedure, but to date has not been used on a machine vacuum system of this size. Laboratory tests⁽⁵⁾ have shown that in-situ argon glow discharge cleaning can reduce the desorption coefficient from 10^{-1} molecules/electron⁽⁶⁾ for a mildly baked system, to 10^{-7} molecules/electron for an ion dose of 8.9×10^{18} ions/cm². For the NSLS X-ray storage ring, this means reducing the total gas desorption from 0.108 Pa m³/sec, (0.75 Tl/sec), to 8.5×10^{-7} Pa m³/sec, (5.9×10^{-6} Tl/sec). Laboratory tests will be performed to study this procedure.

Vacuum Chamber

The storage ring vacuum chambers will be fabricated from an aluminum extrusion, alloy 6063-T4. Where possible, the chambers will be welded together, in-situ, to reduce the number of flanged joints. Aluminum to stainless steel transition material will be used to join stainless steel flanges and bellows to the chamber. These transitions are available as explosion bonded, roll bonded, friction welded and DEPI welded⁽⁷⁾. All four types are being evaluated and the most suitable material(s) will be used. Figure 2 shows the vacuum chamber extrusion cross-section.

An aluminum extrusion was chosen over a fabricated stainless steel vacuum chamber because:

1. It makes possible a design that minimizes changes in chamber cross-section that tend to excite RF losses.
2. Simplifies the cooling by incorporating cooling channels in the extrusion.
3. Aluminum is an excellent UHV material having a low outgassing rate after conditioning⁽⁸⁾.

Chamber Cooling

Cooling of the general run of vacuum chamber is via two water channels in the extrusion. Experience with water cooling aluminum in nuclear reactors has shown that the cooling water should be slightly acidic, $\text{ph} = 5$, to minimize corrosion.

As noted above, synchrotron radiation occurs when the electron is accelerated through a curved path. This occurs in the dipole bending magnets. Extrusions will have integral cooling channels for sections that traverse dipole magnets. For straight sections, cooling channels are eliminated.

In the X-ray ring, a water-cooled copper block must be used at the crotch of each beam port in place of the aluminum extrusion which would melt at this location. This area is now under development and will be reported on at a later date. A proposed design is shown in Fig. 3.

Pumps

Distributed ion pumps will be used in all bending magnet vacuum chambers. Figure 2 shows such a pump in the pump chamber of the aluminum extrusion. Slots will be punched in the web separating the pump chamber from the beam chamber. The effective pumping speed of the distributed ion pump, adjusted for the conductance loss through the slots, is calculated as 200 liter/sec/meter for nitrogen at 10^{-7} Pa (10^{-9} Torr). The pump will operate in a magnetic field of 1.03 Tesla (10.3 k gauss) with a cell size of 11 mm diameter x 22 mm long. Titanium cathodes are planned, but consideration is being given to using titanium and tantalum cathodes to increase the argon pumping speed. Operating voltage is 5 kV.

Lumped Pumps

To increase the pumping speed downstream of the bending magnets, where the gas load will be high due to radiation, conventional sputter-ion pumps (lumped pumps) will be used. These pumps will also maintain the vacuum

during non-operating periods when the magnets are not energized.

Titanium Sublimation Pumps

Provisions will be made for installing titanium sublimation pumps downstream of the bending magnets. These pumps will only be used in the 10^{-7} Pa (10^{-9} Torr) range. Multifilament type pumps will be used so that the system would not have to be vented should a filament burn out.

Roughing Pumps

To completely eliminate the possibility of oil contamination, an oil-less roughing system will be used. At present, an air bearing turbomolecular pump, backed with a carbon vane mechanical pump and a cryo-sorption pump is being considered. The turbomolecular pump will be necessary for argon glow discharge conditioning, as well as for pumping to 10^{-4} Pa (10^{-6} Torr) for starting the ion pumps. If necessary, the turbomolecular pump may be left running without fear of contaminating the system or the necessity to keep liquid nitrogen traps filled.

Valves

Initially, no in-line valves will be installed in the VUV ring, and only four will be used in the X-ray ring. This is not because additional valves are not desired, but because present commercial valves do not meet such requirements as: all metal construction, radiation resistance, minimum RF losses, etc. Valves are now being developed commercially to meet these requirements and will be installed in the future when their reliability is assured.

3. Computer

A computer terminal will be located at each roughing station. From these locations it will be possible to manually monitor and control all of the vacuum valves, pumps, and gauges.

In addition, the computer will be used to routinely monitor and store pressure data and the general status of the various systems, and take corrective actions when necessary.

4. Experimental Beam Lines

A total of 44 experimental beam lines will eventually be installed on the storage rings, 16 on the VUV ring and 28 on the X-ray ring. This does not include six additional short wavelength beams, called "wigglers".

Pressures in the experimental lines will vary depending on individual experimental requirements. Pressures will range from 10^{-8} Pa (10^{-10} Torr) for X-ray absorption experiments, to 133 Pa (1 Torr) for gas phase experiments.

With this number and diverse use of beam lines, strict control is necessary over vacuum operation and procedures to prevent catastrophic vacuum failure. Residual gas analyzers and vacuum gauge interlocks will be incorporated into each beam line to protect the storage rings from contamination and accidental vacuum failures.

Figure 3 shows schematically the beam line components that are common to all experimental beam lines. The shutter is a water cooled device to stop the radiation from damaging the UHV valve when it is closed. The purpose of the fast valve is to prevent an accidental beam line failure from destroying the storage ring vacuum. Designs are in process for a valve with a 3 - 5 msec closing time.

Still unresolved is the design for an efficient non-contaminating vacuum system for experiments that require corrosive gases, large quantities of combustion products or noble gases.

Acknowledgement

The authors wish to thank members of the vacuum groups at Cornell University, SLAC, University of Wisconsin, CERN, Daresbury, and DESY who have investigated, designed and built similar machines, and have freely assisted the NSLS staff with both information and hardware.

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Figure Captions

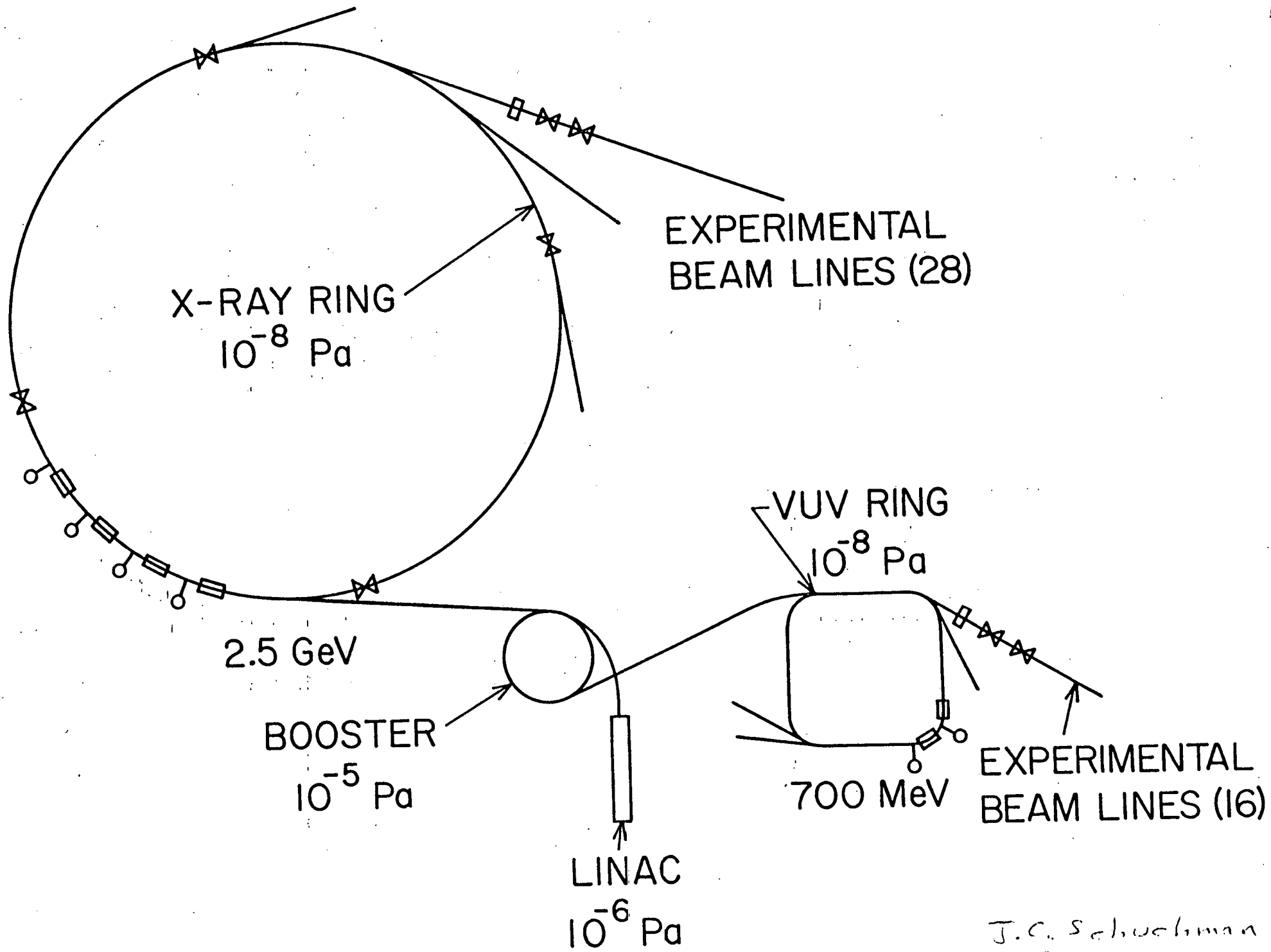
- Fig. 1. NSLS Vacuum System Schematic.
- Fig. 2. Vacuum Chamber Extrusion with Distributed Ion Pump.
- Fig. 3. Beam Port Crotch Cooling.
- Fig. 4. Schematic of Experimental Beam Line.

TABLE 1

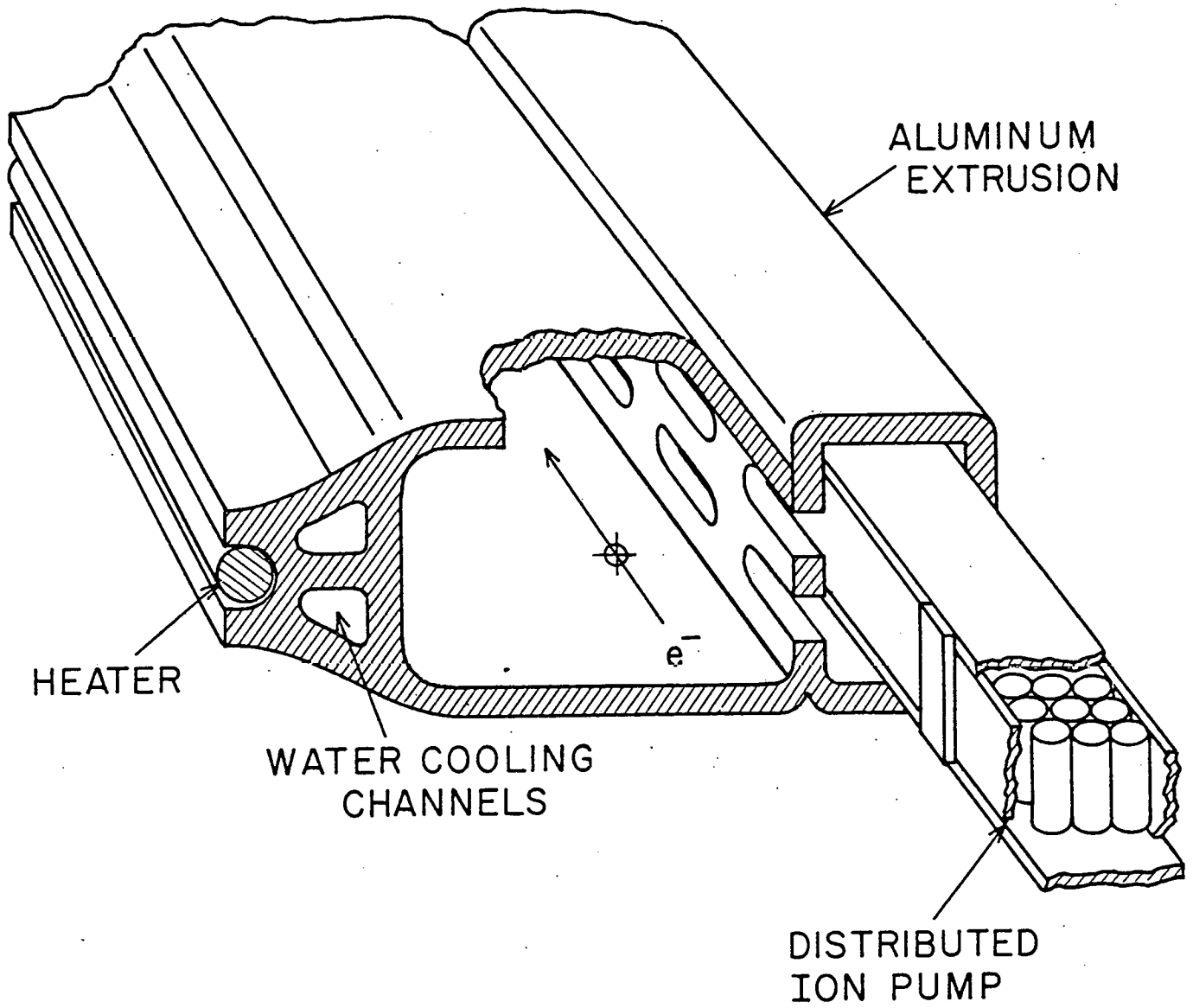
NSLS Vacuum System Parameters

	<u>Booster</u>	<u>VUV Ring</u>	<u>X-Ray Ring</u>
Circumference, m	30	51.7	170.5
Cross Section, mxm	30 x 112	42 x 80	42 x 80
Material	S/S-316	Al 6063-T4	Al 6063-T4
Dynamic Gas Load,*			
Tl/sec	---	5.6×10^{-6}	2.8×10^{-5}
Total effective pumping speed, l/sec			
Sputter-ion pumps	800	880	2,640
Distributed ion pumps	---	2880	10,300
TSP	---	2800	5,600
Operating Pressure, Pa			
beam off	10^{-5}	2×10^{-8}	2×10^{-8}
beam on	10^{-5}	2×10^{-7}	2×10^{-7}
Number of inline valves	0	0	4
Beam Energy, GeV	.700	.700	2.5
Current, ma		1000	500
Critical wavelength, Å	---	2	14
Wavelength range, Å	---	12-1200	1-12
Total Radiated Power, kW		11.1	252
Power on chamber wall, W/cm	---	9.1	48
Bending Magnet Radius, m	1.91	1.91	6.875

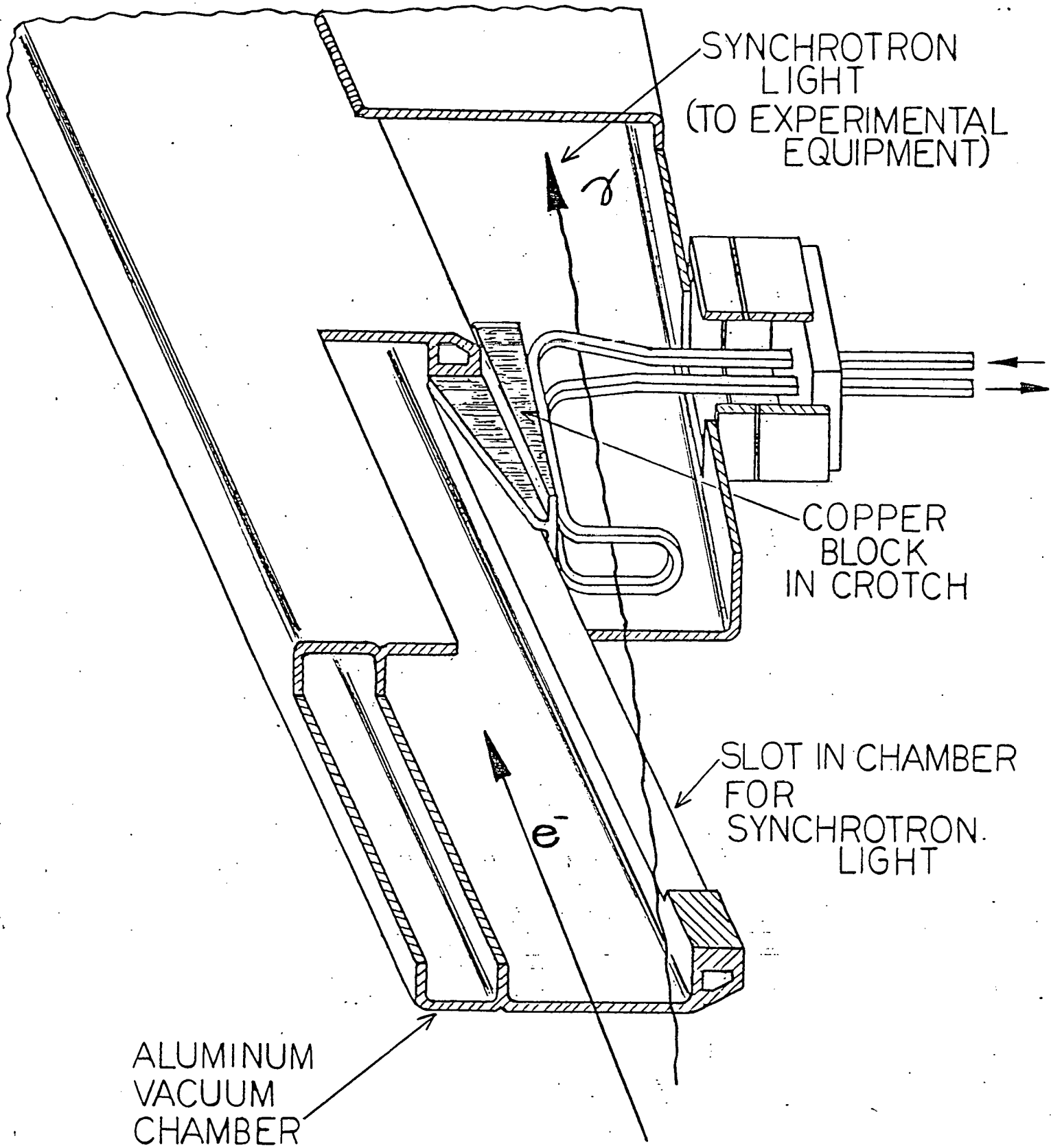
* After Argon glow discharge



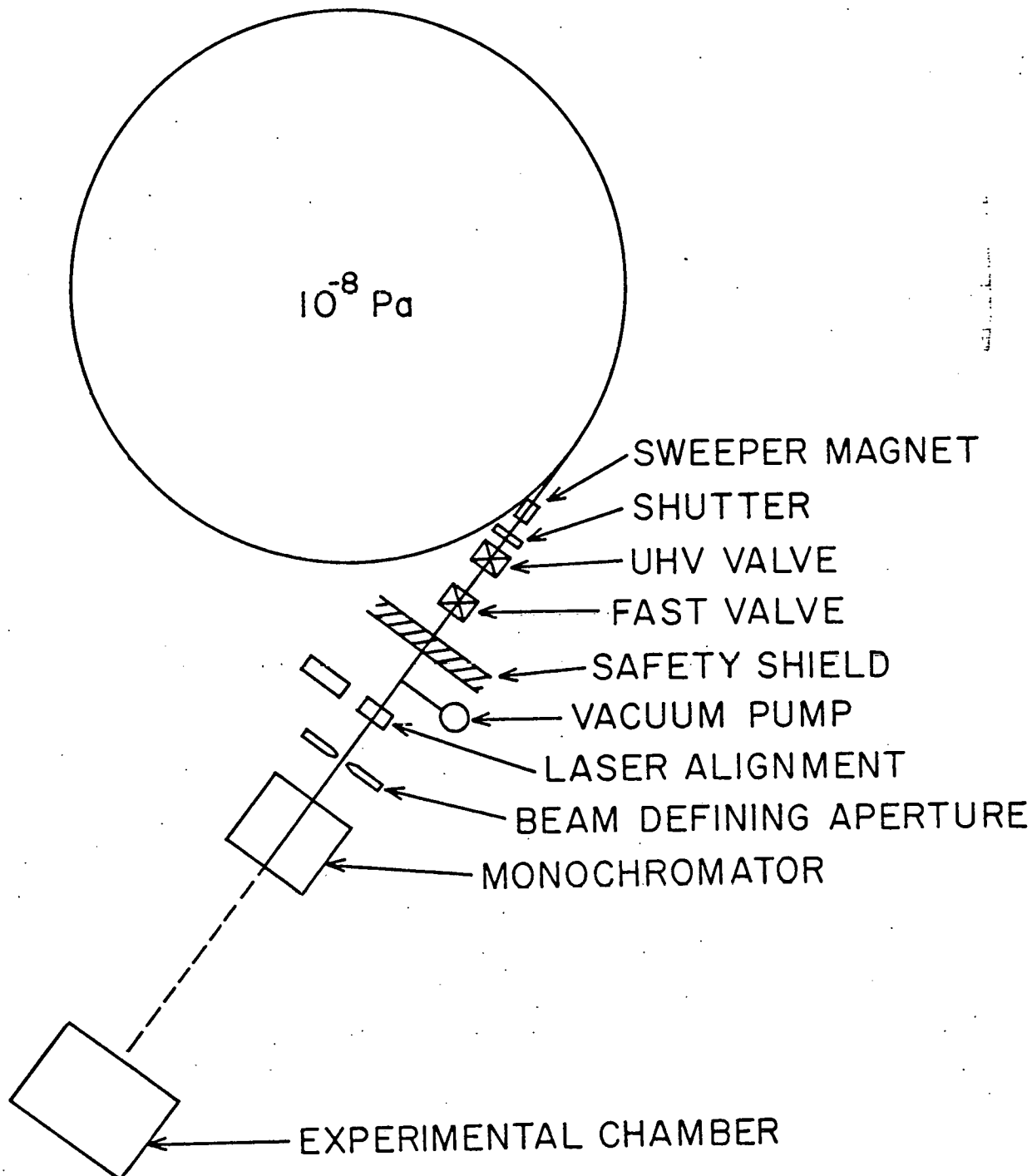
J.C. Schwuchman
Fig 1



J. C. Schuchman
Fig 2



J.C. Schuchman
FIG. 3



J. C. Schuchman
 FIG. 4