Cliff Olson

A PROPOSAL

TO

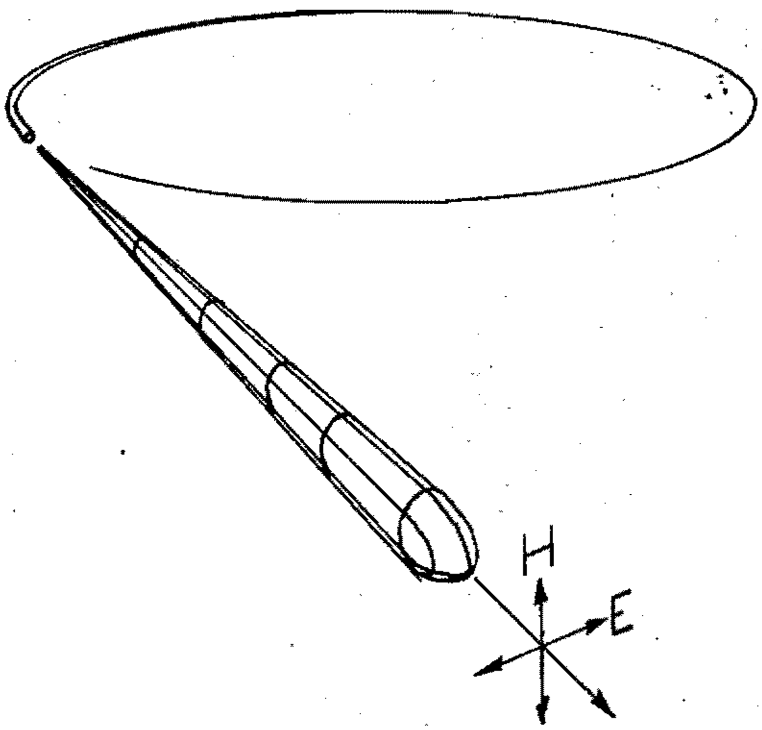
THE NATIONAL SCIENCE FOUNDATION

FOR THE EXPANSION OF THE SYNCHROTRON RADIATION CENTER

OF THE UNIVERSITY OF WISCONSIN-MADISON

December 1, 1976

The Synchrotron Radiation Center Staff



THE SYNCHROTRON RADIATION CENTER

PHYSICAL SCIENCES LABORATORY
University of Wisconsin
P.O. Box 6
Stoughton, Wisconsin 53589

A PROPOSAL

TO

THE NATIONAL SCIENCE FOUNDATION

FOR THE EXPANSION OF THE SYNCHROTRON RADIATION CENTER

OF THE UNIVERSITY OF WISCONSIN-MADISON

Principal Investigator

Ednor M. Rowe
Chief Scientist
Social Security No.: 544-32-8511

New Proposal to NSF

Amount Requested: $2,930,000

Proposed Starting Date: October 1, 1977

Proposed Duration in Months: 30 Months

Endorsements:

Principal Investigator
Ednor M. Rowe

Chief Scientist
873-6651, Area 608
Date: 12/10/76

Department Head
Murray A. Thompson

Director, Physical Sciences Laboratory
873-6651, Area 608
Date: Dec 22/1976

Robert M. Bock

Dean, Graduate School
262-1044, Area 608
Date:

Robert W. Erickson

Director, Research Administration
262-3822, Area 608
Date:

University of Wisconsin-Madison
COMPUTING AND DATA PROCESSING -
Equipment Acquisition and/or Use of Outside Services
(see over for instructions)

CCA No. 503

1. Request for:
☐ Action (Reqn. No. ______ attached)
☐ Review (Prior to release of funds)
☒ Approval (for inclusion in proposal for off-campus funding)

2. Date originated 12/15/

2a. For acquisition based on previously approved proposal for funding, show earlier CCA # ______

RECEIVED
DEC 15 1976
RICHARD R. HUGHES

3. Department or Project (and Campus Address):

Physical Sciences Laboratory

4. Estimated Cost (or saving):

$212 K

☒ One-time
☐ Monthly
☐ ______

5. Equipment or Service Requested:

On-line computer with necessary CAMAC and microcomputers.

6. Telecommunication (TC) Aspects
☒ None
☐ Routine (and TC Eqpt<$3000 or $250/mo)
☐ Other - check if you have:
☐ consulted TC Office (262-6540)
☐ submitted TSSR to TC Office

7. Program and Need:*

To control and gather data from a synchrotron ("Aladdin") at the Synchrotron Radiation Center. Both operations will use on-line connections and will include both CAMAC and microcomputers. The total cost of the synchrotron is $2,930,000.

8. Justification of Proposed Solution:*

See attached letter.

9. Alternatives Considered and Why Rejected:*

The 1110 Univac cannot control the synchrotron. If the proposal is accepted, the system will be chosen after competitive bidding. Final approval for purchase will then be requested from the Coordinator of Computing Activities.

10. Source of Funds and Budget Reference:

National Science Foundation

11. Submitted by: Murray A. Thompson
(Address: Physical Sciences Laboratory)
(Telephone: 873-6651)

12. Other copies desired (Include address):

Approval (with comments and limitations, if any)

Richard R. Hughes 12/15/76
Coordinator of Computing Activities Date

Needs Central Administration review? ____ Yes X

approval for proposal - resubmit citing this CCA# when acquisition is planned -

*Attach (& note) supporting documents, if any. If lengthy, note pertinent pages.

TABLE OF CONTENTS

I. The Proposed Project

As a natural evolutionary development of the Synchrotron Radiation Center of the University of Wisconsin, we propose to construct an electron storage ring of advanced design which will provide extremely intense synchrotron radiation over a spectral range extending from the far infrared to the keV x-ray region. In support of this proposal The University of Wisconsin-Madison will undertake the building required to house the storage ring and to provide adequate research, laboratory, and office space for the investigators carrying out research at the facility. Also to be provided by The University of Wisconsin-Madison is complete access to the services and facilities of the Physical Sciences Laboratory of The University of Wisconsin-Madison in support of the construction of the proposed storage ring. While the construction and procurement of experimental apparatus for the research programs to be carried out upon completion of the expanded facility does not form part of this proposal, equipment sufficient to implement fourteen experimental stations at the proposed storage ring will be available from the existing Synchrotron Radiation Center (Tantalus I) at the time of commissioning of the proposed storage ring.

Experience gained during the eight years that the Synchrotron Radiation Center of the University of Wisconsin has been in operation as a national facility has shown that while a high energy storage ring can provide usable vuv and soft x-ray radiation in addition to the intense, kilovolt x-rays for which it is designed, such an answer to the rapidly increasing national demand for access to intense synchrotron radiation sources in the 10 to 1000 eV range is neither optimum nor economical. Therefore, the system that we have designed consists of a 100 MeV race track microtron injecting into a 750 MeV intermediate energy storage ring which is designed to be an intense source of vuv and soft x-rays to an energy greater than one keV. This ring, which has been named Aladdin, will meet the presently forseeable spectral and intensity requirements of the research programs it is designed to serve without recourse to special elements (wigglers, etc.). However, provision is made in the design of the ring for the installation of these special elements should this prove desirable after the storage ring system is complete. One of the special elements that might be installed in the future, the helical wiggler, places stringent requirements on the injector for the machine in which it is installed, requirements that can only be met by using another storage ring as the injector. Should the need to meet such requirements for the Aladdin arise, Tantalus I, the 240 MeV storage ring now in operation at the Synchrotron Radiation Center, will be used as a damping booster to inject into Aladdin.

Aladdin, as designed, will be 60 meters in circumference and will be equipped with 12 ports capable of passing 42 milliradians and 12 ports each capable of passing 120 milliradians of the synchrotron radiation pattern produced by the machine. Each of the ports may serve one or more beam lines depending on the development of research needs. Two long (four meters clear length) straight sections, easily convertible to low β configuration, for the installation of special elements such as transverse wigglers are included in the lattice. All synchrotron radiation source locations of the electron orbit in the magnet arcs are at points such that σ_x and σ_y, the standard deviations of the electron beam envelope, are at or near minima and their derivatives, $\sigma_{x'}$ and $\sigma_{y'}$, are vanishingly small.

A variant of the proposed machine, called Super Aladdin, which would be implemented after the commissioning and "running in" of Aladdin through the installation of additional focusing elements in the basic Aladdin structure, will increase the brightness of the machine by a factor of approximately six.

The radio frequency accelerating system for the machine will operate at a frequency of approximately 50 MHz to minimize beam cavity interactions which could adversely affect the small electron beam cross sections that are important features of the proposed storage ring.

A computer which will be available during stored beam time to the users for data handling and reduction on a time shared basis, will be used to monitor and control the storage ring and its injector.

Although the performance of the storage ring system will be very high, the design of the system is essentially conservative. Extreme state-of-the-art design has been avoided intentionally in the interests of achieving superb performance in a minimum amount of time upon the completion of the construction period which is estimated to be two and one-half years.

While Aladdin is designed primarily to be an advanced synchrotron radiation source, it could serve as a high performance booster for injection into a 2.5 to 3.0 GeV storage ring designed specifically to be an intense source to 40 keV and beyond should the needs of the research program at the Synchrotron Radiation Center of The University of Wisconsin-Madison justify such an expansion in the future.

The proposed facility will require a building to house the storage ring, its associated support equipment and experimental areas. Funds for the construction of this building will be made available by the Graduate School of The University of Wisconsin-Madison.

The storage ring building will be a single story steel framed insulated metal building (160 feet by 136 feet) with a fully excavated poured concrete basement. The basement floor will be poured on bedrock providing a stable platform for the ring and experimental equipment. The storage ring and experimental area will be 160 feet by 95 feet with a 20 foot ceiling height. This area will be served by three 2-ton cranes. The remaining 160 foot by 41 foot space will be for loading, experimental set-up, power room, and experiment storage. The two basement areas will be separated by a two foot thick concrete shielding wall. The area above the 160 foot by 41 foot section will be the above grade structure containing the control room and offices.

The entire facility will be heated and air-conditioned to maintain an environment compatible with the needs of the optical equipment which will be in use. All spaces will be protected by a fire alarm system.

II. Justification and Need for the Proposed Project

A. Scientific Justification for the Proposed Project

Synchrotron radiation has proven to be one of the most powerful probes of the electronic and structural properties of matter available today. There is a strong consensus in the scientific community, as has recently been documented in a National Academy of Science report[1], that research programs in physics, chemistry, materials science, biological sciences, metallurgy, and in other disciplines are profiting from the unique characteristics of synchrotron radiation. Indeed, all studies where an understanding of the electronic properties of a system is of importance are being affected, and the promise for future application to such efforts is extraordinary. A few of the research areas which investigators are presently profiting from access to the intense continuum source are: the optical properties of ordered metals, alloys, semiconductors, and insulators, and of amorphous materials; surface studies involving a freshly cleaved surface and its interaction with chemisorbed and physisorbed atoms or systems; catalysis and catalytic behaviors; the physics and chemistry of the gas phase (atomic, molecular, molecular clusters, aerosols, colloids, etc.) including all studies which relate to the energetics of electronic processes in gas phase systems; the biological aspects which use the radiation for structural analysis and dynamic behaviors; and the science and technologies which stand to profit from x-ray lithography and micrography techniques. It is important to note that these studies are multidisciplinary, and that therefore synchrotron radiation is providing a common channel for communication between fields of research which have historically been isolated from one another.

Work in the vuv/sxr portions of the spectrum in all of these areas has been vigorously pursued at the Synchrotron Radiation Center. The Center has been in operation for 8 years and during this time has been the proving ground for many of the powerful experimental techniques now in general use there and elsewhere[2].

Scientists working in the atomic and molecular sciences stand to profit from access to intense synchrotron radiation vuv/sxr sources. For their efforts to be successful in the experiments now being designed, an intense continuum source with a highly polarized, well-collimated beam is absolutely necessary. Their samples or targets are atoms, molecules, radicals, or ions which are to be excited by photoabsorption, then ionized (singly or multiply) or photodissociated. Essential information about the energy levels of the systems, the transition probabilities from one state to another, the lifetimes of the excited states, the rate constants, and the energy-dependent cross sections for photoabsorption can be obtained.

A very intense synchrotron radiation source is necessary for these studies since high resolution (up to $\sim 5 \times 10^5$) for atomic and molecular experiments is required. The intense, polarized photon beam produced by the modern electron storage ring makes it possible to study spatial distributions of photoionization fragments. With the well-defined time structure of the radiation from synchrotron sources, it is possible to pursue fluorescence measurements and lifetime studies.

These efforts are now concentrated in the vuv and sxr portions of the spectrum, and must be encouraged not only for scientific reasons but also for environmental considerations. In spite of agressive synchrotron radiation research efforts, there remain a great many common atmospheric gases whose absorption kinetics and fragmentation characteristics are not well-known; among this latter group must be included in the fluoro- and chlorocarbons which are thought to be important in the degradation of the ozone mantel of the atmosphere.

Excited state gas phase spectroscopy promises to be an active area for vuv/sxr research in the future. Techniques for the study of absorption in high temperature atomic and molecular vapors are being developed, thereby increasing the number of systems that can be investigated[3]. Experiments have been proposed in which the system under study is excited by a tunable dye laser synchronized to the storage ring beam, allowing the interaction of the photon beam with the excited state to be studied. Continued efforts involving an intense and polarized photon beam and ion beams, molecular clusters, or beams of short-lived radicals should be highly productive. The simultaneous emission of two or more photons or fragments following an ionization event can also be studied.

The further development of ion and excited state spectroscopies should increase the present level of interest and extend it beyond the 3000-300 Å range to the 300-30 Å portion of the spectrum. Luminescence measurements with solids will similarly continue. Fluorescence lifetime measurements and measurements of the time-dependent emission spectra from polymer materials will be possible by making use of the time structure of the intense, polarized photon beams available from a storage ring. These measurements exploit the natural tendency of molecules to rotate or randomly reorient, so the depolarization of the fluorescence spectrum would be a measure of the rotational processes involved.

Efforts at understanding the solid state or condensed phase of matter are now intense and can be expected to become more so as higher intensity sources become available. Reflectivity and absorption measurements have been traditional strong users of synchrotron radiation and will continue to be[4]. These measurements give important information regarding electronic properties, one-electron band structues, many-body edge effects, plasmon features, and optical constants of materials which are of scientific and technological importance.

The use of synchrotron radiation in modulation spectroscopy has been developed by scientists at the Synchrotron Radiation Center[5-18], and the further application of this technique should be valuable in more accurately defining the electronic structures of many solids. Electroreflectance[5], thermoreflectance[6], and piezoreflectance or stress modulation will doubtless continue[7]. Magneto-optical studies[8] have recently been shown to be feasible with synchrotron radiation at the Synchrotron Radiation Center, and these will be of great value in studies of Ni , Fe , Co and the magnetic rare earth metals. Since these techniques measure an ac component of the reflected beam which is related to a small modulation of one of the internal parameters of the sample, they require a very intense and very stable photon beam because the signals which are measured are typically a few parts in 10^5.

EXAFS (Extended X-ray Absorption Fine Structure) measurements are an extension of transmission or absorption measurements to shorter wavelengths and have proven to be of great interest and value in a variety of studies. With access to an intense source of radiation that extends beyond the carbon K edge (~ 44 Å) to the one kilovolt x-ray range, EXAFS studies with less tightly bound core levels would be pursued to advantage[9].

Photoelectron spectroscopies provide means for studies of both the gaseous and condensed phases of matter. Much of the pioneering work with UPS techniques using synchrotron radiation has been performed at the Synchrotron Radiation Center[2], and this work is likely to continue at greater levels as the photon flux available and wavelength range covered increase. Partial yield or photoyield spectroscopy[10] provides the distribution of electrons emitted as a function of photon energy. In the vuv and sxr, the partial yield closely resembles the absorption coefficient and provides a valuable way of observing core structures in highly ordered crystalline samples. Constant initial-state-energy spectroscopy[11] involves scanning the photon energy and the retarding voltage of the electron energy analyzer synchronously and requires continuum sources with the highest flux possible. Constant final-state-energy spectroscopy[11] similarly involves scanning photon energy. These experimental methods are very valuable in charting the development of optical absorption structures and assessing the importance of particular sets of initial and final states. These techniques are applicable to all types of solids and are therefore very powerful. In particular, they complement conventional photoelectron spectroscopies which study the kinetic energy distributions of emitted electrons at fixed incident photon energy.

An extremely interesting development in photoelectron spectroscopies has involved the angular selection of emitted electrons. This is the technique of the angular resolved ultraviolet photoelectron spectroscopy (ARUPS)[12] in which the collection of emitted electrons is restricted to those possessing a particular initial state momentum as well as energy. These studies not only hold great promise for unraveling the details of electronic properties of solids, but they are also exciting for studies of surfaces and surface kinetics. Surface bond orientations and strengths and their dependence on surface coverage are of great importance in materials science studies of surface properties and thus will have profound implications in catalysis and catalytic processes. In all of these studies, an intense, polarized photon beam is necessary since the number of emitted electrons into the analyzer window is small.

In existing photoelectron studies, those performed with radiation from Aℓ K_α x-ray line source (photon energy 1486 eV) have been termed XPS. Much of the distinction between UPS and XPS is lost, however, when access to a medium energy, high intensity storage ring source is possible. We have emphasized the range $\lambda \geq 10$ Å - and by that definition, all existing XPS work would be included in the sxr range and lies well within the capability of an intermediate energy storage ring.

A development which should greatly enhance UPS and XPS studies involves the use of visual display methods for investigating the angular distribution of photoemitted electrons. Again, the demands on the photon source are primarily that it be continuous in energy and extremely intense. Another interesting development which has been shown to be feasible but has not yet been fully exploited involves the use of UPS for surface elemental mapping. This photoemission electron microscopy involves the analysis of the emission image as a function of photon energy. High intensity of the beam is again of prime importance.

Another characteristic of synchrotron radiation, the use of which has been pioneered at the Synchrotron Radiation Center, is its capability to function as an absolute standard for radiometry purposes[13]. The radiation output is readily calculated when the circulating beam current is accurately known. With a storage ring source, other sources and detectors which are used in a variety of applications in science and technology can be readily calibrated.

Radiation damage can be studied in solids since the intense photon beam can be used to create color centers, paramagnetic radicals, etc.[14]. For many of these measurements, a high intensity source is necessary.

X-ray and soft x-ray lithography and micrography[15] can be readily performed with an intense synchrotron radiation source. The lithography technique is a simple one and involves exposing a photosensitive plate with the sample to be studied or duplicated above it serving as a mask or master. Hence, an exact copy of the sample is produced with high precision and great speed. The applications of this technique are great both in scientific contexts and in microcircuitry technologies. With lithography techniques, it becomes feasible to mass-produce circuit elements that are limited only by the techniques for producing the master (electron beam etching, etc.). However, much challenging fundamental and applied research in materials science and technology must be carried out before this promise is realized. The materials science group at The University of Wisconsin-Madison is now organizing a broadly based program in these areas and a discussion of their plans is given in Appendix II .

In addition, lithography and micrography offer the potential of studying dynamic behaviors both in materials science and in biological studies. Phase transformations, studies of defects in fabrication, and studies of polymers could be pursued to great advantage.

It has been pointed out[16], and is an intriguing possibility, that the scattering of microwave and laser photons off the electron beam in a storage ring could produce a highly collimated, near mono-energetic beam of x-rays or gamma rays. While the cross section for the process is small ($\sim 10^{-26}$ cm^2), the stored beam would be sufficiently high so that output beam flux studies in the range up to perhaps 30 MeV would be possible. The energy of the output beam could be controlled by varying the incident photon energy or the electron energy. The duty cycle of the resultant Γ-ray beam, which would be the same as that of the circulating electron beam which is bunched, can be as large as 10^{-1}, a value only exceeded by superconducting linear accelerators. In addition, the Γ-ray beam will be uncontaminated by electrons.

B. Applications to Energy Research

It is extremely difficult to separate those aspects of research which are relevant to energy applications from those which are not since most research is multidirectional. This is particularly true with regard to research efforts involving synchrotron radiation.

It is a truism that a wide variety of studies contribute results that have considerable impact on any energy-related decision. Among the studies which have the most profound influence are those which relate directly to the electronic properties of matter, for it is those properties which will dictate a system's behavior and energetics. It is the electrons which respond to external fields; that conduct energy in transmission lines or electrical circuits; that absorb solar energy and are therefore important in energy storage cells; that determine a material's behavior when heated to elevated temperatures; that dictate whether a system will exhibit superconductivity; that define the behavior of aerosols or colloids; that are involved in catalytic behavior; that participate in energy synthesis and reactions in biological systems; that define the characteristics of a surface and hence its reactivity and corrosion properties; that are involved in processes at interfaces in solid state devices; etc. If the electronic properties of the system are not known, the prediction of the usefulness of the system in technological applications is extremely difficult.

Research efforts which exploit synchrotron radiation are largely devoted to studying the electronic properties of matter in its many forms (gas, molecular cluster, colloid, crystalline and amorphous solid, surface, etc.) and are carried out by studying the interaction of electromagnetic radiation with the system. Optical reflectivity and absorption; photoelectron spectroscopies; atomic absorption and excitation and ionization; crystal structure measurements; topographical analyses and time-development studies -- these are all researches which ask the fundamental question: How will the system respond to electromagnetic radiation, whether it is ultraviolet light, soft x-rays or hard x-rays - how will the energy be absorbed and once absorbed how will the energy be transported about the system?

Synchrotron radiation is an absolute necessity in these studies of matter. It makes it possible to bring a host of techniques to bear on problems of scientific and technological interest. A facility which provides synchrotron radiation to the community makes it possible to attack technical problems in an efficient and powerful way.

Direct examples of synchrotron radiation efforts which bear on energy problems are numerous. Optical studies involving reflectivity and absorption measurements give direct information about the optical constants, and these are measures of how much solar energy a system will absorb and how efficiently it can do so. These studies make it possible to design complex composite systems to be used in absorbing, storing, and transporting solar energy. Such studies are also important in determining the high temperature behavior of systems since emissivity can be calculated from optical constants and the emissivity determines how much energy will be lost due to blackbody radiation.

Photon and photoelectron spectroscopies depend critically on a suitable source for radiation, and such studies provide detailed information on both bound and continuum levels of atoms, molecules, ions, and the solid state. Further, research on atomic and molecular interactions, and studies on molecular structure, including very short-lived reaction intermediates, can be carried out at the proposed facility.

Metallurgical studies stand to profit enormously from the availability of an intense radiation source. Metallurgical processes such as the tendency for surface faceting, the formation of grain boundaries in polycrystalline materials, and solid-state interfaces in composite materials can be investigated. Corrosion and oxidation can be studied in materials of importance. Time development or dynamic effects in solids such as crystalline growth, fatigue, creep, etc. can be studied in ways not possible with other photon sources.

Catalytic studies are exciting and are urgently required in our high technology society. Synchrotron radiation provides a powerful probe for studying the kinetics and dynamics of catalytic processes. Since the surface is all-important in catalysis, surface-sensitive measurements such as ultraviolet and x-ray photoelectron spectroscopy are invaluable. Electron micrography can be used to advantage to study surface constituents and composition.

Radiation damage can be studied with high intensity photon beams from a storage ring. The data gained are directly relevant to the CTR program and to laser fusion efforts. Studies of gas desorption by intense radiation beams are relevant to the CTR program. Information gained in these studies very probably will have important application in the development of high efficiency devices utilizing solar energy directly to hydrolize water.

Materials of interest in superconductivity are being studied with synchrotron radiation. The data resulting from optical and photoelectron studies make it possible to understand the electronic energy states, the knowledge of which is critical in superconductivity. Further, crystallographic and topographical data make it possible to produce better-characterized superconducting devices.

Combustion or rapid-oxidation processes can be better understood by studying molecular beams and aggregate systems with synchrotron radiation.

Studies of gas kinetics and reactions are very important in understanding the atmosphere about us. Of immediate importance is the influence of aerosols and SST pollutants on the ozone mantel above the earth.

Synchrotron radiation research efforts have had tangible impact on the technology of today and the decision-making processes involved in energy research and development. The development of further synchrotron capability can only enhance the impact in the future. It should be borne in mind that experiments relevant to every application listed in this and the previous section are either now being performed or are in preparation at existing synchrotron radiation facilities.

C. The Synchrotron Radiation Center of The University of Wisconsin-Madison in Relationship to Other U. S. Synchrotron Radiation Facilities

At the present time, research utilizing synchrotron radiation is carried out at four facilities in the United States. These facilities are located at the University of Wisconsin, the Stanford Linear Accelerator Center, Cornell University, and the National Bureau of Standards. Of these, the first three are supported in part or in total by the National Science Foundation, the fourth being supported by the Department of Commerce. The facilities at the Stanford Linear Accelerator Center (SSRP) and the Cornell Synchrotron are parasite operations - the operation of the machines used as synchrotron radiation sources at these facilities being funded primarily for high energy physics research. The machines used at the Wisconsin Synchrotron Radiation Center and the NBS Synchrotron Ultraviolet Radiation Facility are dedicated machines, i.e. the function of these machines is limited to providing synchrotron radiation for the vacuum ultraviolet and soft x-ray research programs being carried out at the facilities that they serve. The research facility at the Cornell Synchrotron is at present small, serving a single in-house group for investigations at 30 keV and higher energies. The SURF facility at the NBS is larger but, while plans do exist for making access to this facility available to other groups, during the near future this facility will continue to be used by Madden and his co-workers primarily. Neither the Cornell nor the NBS facilities are likely to become capable of supporting research programs of the extent and variety that are currently underway or being planned at the Wisconsin and SSRP synchrotron radiation centers in the forseeable future. Thus, they are not likely to provide a large fraction of the national capacity to support synchrotron radiation research.

The Wisconsin and SSRP facilities are national facilities funded by the NSF to serve all qualified investigators. The Wisconsin Radiation Center, which has been in operation for eight years, serves the needs of a large and growing number of investigators working in the vacuum ultraviolet and soft x-ray ranges up to approximately 300 eV. The electron storage ring at the Radiation Center, Tantalus I, fulfills the requirements of a wide variety of investigations for a stable, intense, continuum source of electromagnetic radiation over a wavelength range extending from 5 nm to 300 nm. It also provides usable photon flux into the far infrared (200 μm). Areas in which investigations are presently being carried out at the Radiation Center include

1. High resolution absorption spectroscopy of solids and gases
2. High resolution reflectance spectroscopy of solids
3. Electron photoemission spectroscopy of solids and gases with variable photon energy
4. Photo induced luminescence in solids and gases
5. Photoabsorption, dissociation, and ionization cross section measurements

6. Physisorption studies
7. Chemisorption studies
8. Thermo-modulation reflectance spectroscopy
9. Electro-reflectance spectroscopy
10. Magneto-reflectance spectroscopy
11. Magneto-transmission spectroscopy
12. Standard light source applications
13. Angle-resolved photoemission with gases
14. Angle-resolved photoemission with solids

A list of the groups scheduled to use the Radiation Center during the period September 1, 1976 - August 31, 1977appears below.

Principal Investigator	Institution	General Area of Interest	Funding Agency
E. Arakawa	Hollifield National Labs	3	ERDA
D. E. Aspnes	Bell Labs	9	Bell Labs
A. Balzarotti	U. of Rome	2	NATO
*G. M. Bancroft	U. of Western Ontario	3	NRC - SRC
R. J. Bartlett	Los Alamos Scientific Lab	2	ERDA
J. Berkowitz	Argonne National Lab	5,13	ERDA
M. J. Berry	U. of Wisconsin-Madison	4	AFOSR
F. C. Brown	U. of Illinois	1,2,11	NSF
T. A. Callcott	U. of Tennessee	2	NSF
R. N. Dexter	U. of Wisconsin-Madison	1,2,3	------
D. E. Eastman	IBM	3,6,7,14	IBM - AFOSR
J. L. Erskine	U. of Illinois	10,11	NSF
E. T. Fairchild	U. of Wisconsin-Madison	12	NASA
** T. Gustafsson	U. of Pennsylvania	3,6,7	NSF
R. M. Hexter	U. of Minnesota	4	
D. R. Huffman	U. of Arizona	2	NSF
Z. Hurych	Northern Illinois U.	3,6,7	NSF
A. Ignatiev	U. of Houston	3,6,7	NSF
D. L. Judge	U. of Southern California	1,5	NSF-NASA
M. G. Lagally	U. of Wisconsin-Madison	3,6	NSF
G. J. Lapeyre	Montana State U.	3,6,7,14	AFOSR
D. Lichtman	U. of Wisconsin-Milwaukee	6,7	NSF
D. W. Lynch	Iowa State U.	1,2,8,9	ERDA
D. S. McClure	Princeton U.	4	NSF
M. Piacentini	U. of Rome	8,9	INRC - ERDA
E. W. Plummer	U. of Pennsylvania	3,6,7,14	NSF
K. Radler	Argonne National Lab - DESY	5,13	ERDA
T. N. Rhodin	Cornell U.	6,7,14	NSF

Principal Investigator	Institution	General Area of Interest	Funding Agency
J. E. Rowe	Bell Labs	6, 14	Bell Labs
J. A. R. Samson	U. of Nebraska	5	NSF - NASA
D. R. Sandstrom	Washington State U.	6, 14	NSF
N. V. Smith	Bell Labs	3, 14	Bell Labs
E. A. Stern	U. of Washington	10, 11	NSF
J. R. Stevenson	Georgia Institute of Technology	1	AFOSR
R. E. Thomas	U. S. Naval Research Lab	3	ONR
J. W. Taylor	U. of Wisconsin-Madison	3, 5	NSF

* Visiting Investigator at the Synchrotron Radiation Center of The University of Wisconsin-Madison, 1975-76.

** Visiting Investigator at the Synchrotron Radiation Center of The University of Wisconsin-Madison, 1976-77.

In addition to the groups listed above, an "in house" group, composed of members of the Radiation Center Operations Group and graduate students, carries out a variety of investigations at the SRC. Among these are optical and photoemission studies of metals in the 2-100 eV range, photoabsorption, photodissociation and ionization cross section measurements in gases in the 20-150 eV range and studies of optical systems for the 10-250 eV range.

The scope and content of the research programs carried out by the users of the SRC continue to grow and mature in a highly satisfactory way, as the Publications List appended to this proposal shows (Appendix I). This is due to both the high quality of the investigators working at the SRC and to the efforts of the SRC Operations Group in the constant improvement of the capabilities of the Radiation Center to support the investigations carried out there.

Photoemission spectroscopy which was initiated at the Center in 1971 by Dean Eastman of the IBM Research Laboratories is now the most commonly used technique at the Center. In the last two years this technique was applied with considerable success to surface studies, an area in which research is now largely carried out through low energy electron diffraction (LEED). In particular, the research programs being carried out by Eastman and Gudat (IBM) on semiconductor surface states; and Hurych and Benbow (Northern Illinois University) on physisorption and chemisorption deserve mention here.

Angle resolved photoemission has become a well established technique at the Center after the initial demonstration of the method by G. J. Lapeyre (Montana State University) and N. V. Smith (Bell Laboratories). A refinement of conventional photoemission spectroscopy, this technique, which exploits the high degree of polarization of synchrotron radiation, is now finding considerable application in solid state investigations, surface studies, and, most recently, gas phase photoemission studies.

Modulation spectroscopy beyond the lithium fluoride cutoff, which was a novelty three years ago, has now reached a rather high degree of perfection: D. Aspnes (Bell Labs) and C. Olson (Ames Laboratory) showed that it is now possible, through these measurements, to assign energies to band structure features within a few tens of millivolts. More recently, these investigators have obtained results of far reaching implications on the ordering of conduction band minima in GaAs through these techniques. While the bulk of these measurements have been carried out so far through thermo or electro modulation, magneto modulation spectroscopy has been demonstrated at the Center in a preliminary but highly successful experiment by J. Erskine, University of Illinois.

The SSRP center, which has been in operation for about two years, serves the needs of investigators working primarily in the 3.5 keV and higher x-ray energy range. That center also has capabilities for supporting research in the vacuum ultraviolet and soft x-ray range, but these cannot at present match the capabilities of the Wisconsin center.

However, the needs of the scientific community for access to radiation sources covering the intense spectral range between 100 and 3000 eV are not being met at any existing facility in the U. S.

Further, both the number of investigators requiring access to the wavelength ranges covered by the existing facilities and the time they require on site will increase dramatically during the next five years. This will come about for several reasons, not the least of which is the very high degree of success so far achieved by those now at work at such facilities both here and abroad. A second and more compelling reason is that more and more applications for synchrotron radiation are being developed as time goes on.

It is expected that the Wisconsin radiation center will continue to develop in the capability to service the needs of the vacuum ultraviolet and soft x-ray community over the next five years, mainly through improvements in source brightness and the quality and quantity of instrumentation available at the Center to investigators. But there are limits beyond which the capabilities of this facility to serve the needs of the scientific community cannot be increased. These limitations are placed by the design of the machine itself and it is primarily because of these limitations that interest in a new synchrotron radiation source has become so pressing. Tantalus I, while probably the most intense source of synchrotron radiation in the 5 to 50 eV range in the world, does not produce sufficient flux for the third generation experiments now being contemplated in the vacuum ultraviolet and soft x-ray range. Furthermore, it is a very weak source indeed at energies greater than 200 eV, a range which is currently being considered as a fruitful area for research.

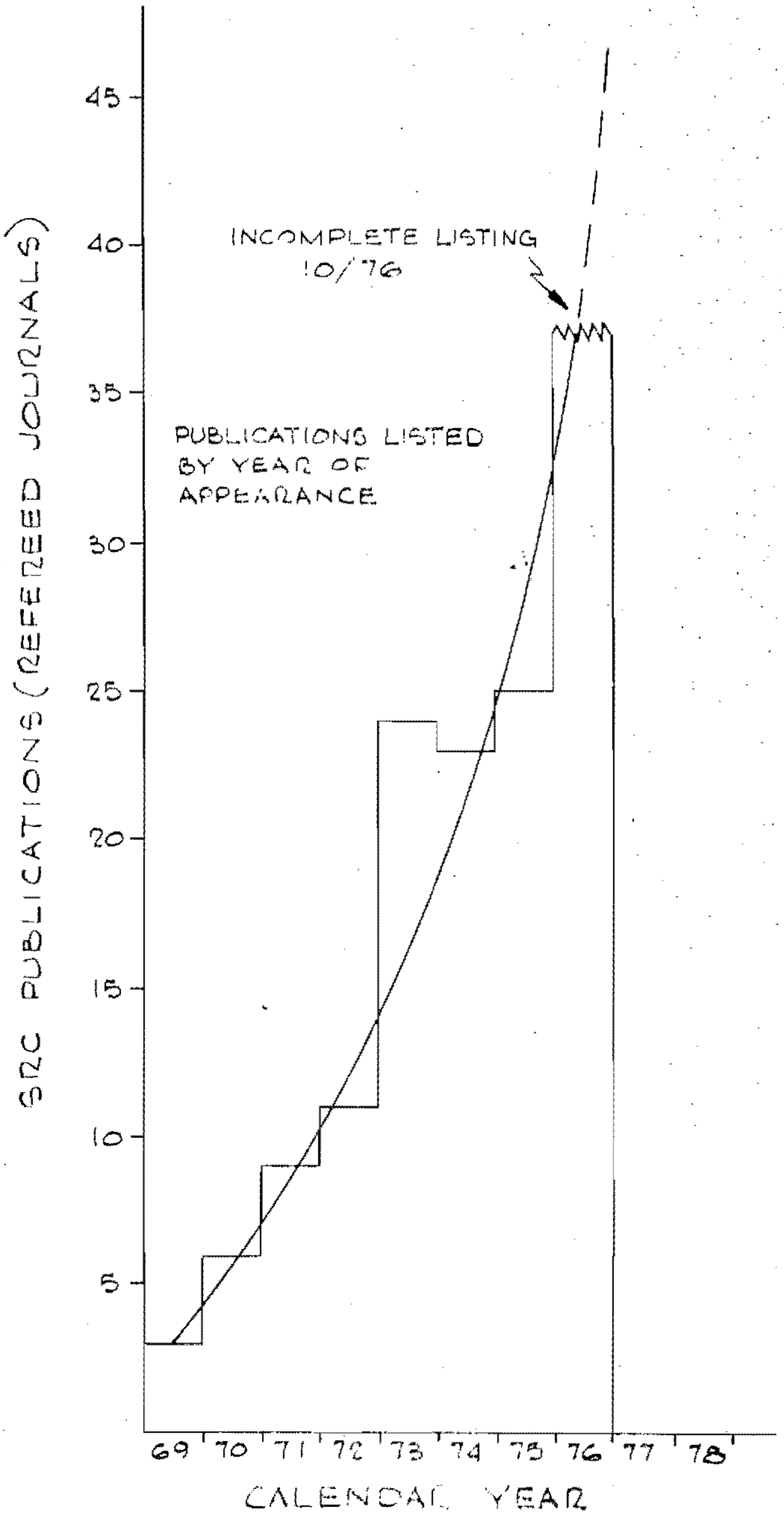
D. Projected Utilization of the Expanded Wisconsin Synchrotron Radiation Center

An assessment of the utilization and needs for synchrotron radiation in this country was completed in anticipation of this document. The projections are based on our evaluation of the impact of synchrotron radiation on various areas of science. They are based on our long-term exposure to users and their expressed needs as well as estimates made by other scientific groups in the U. S. We have also compared our projections of growth to those of our European colleagues and also with those of our counterparts in England.

By 1985 we see a minimum U. S. requirement of 70-75 vacuum ultraviolet and soft x-ray (vuv/sxr) stations. This projection is for a growth factor of four to five in the vuv/sxr utilization. This projection for growth can be justified both by examination of the historical availability of stations in the U. S. and from an examination of the scientific areas and the numbers of scientists that will be affected by access to synchrotron radiation in the energy ranges and intensities available from an electron storage ring.

The historical development of synchrotron radiation in this country led to the early development of vuv utilization beginning about 1962 at NBS. The effort at Wisconsin followed, and the Radiation Center's Eighth Annual Users Meeting was held here in October, 1975, attracting 86 American scientists and 20 foreign scientists. At the present time, the facility at Wisconsin provides stations for 9 vuv experiments. Growth at the facility has been strong. During the 1975-1976 operations period there was a 60% increase in the number of groups requesting access to the Synchrotron Radiation Center of the University of Wisconsin-Madison compared to the 1974-1975 operations period. The mailing list for the annual meeting, which provides an indication of the interest of the scientific community in the experiments in progress at the Radiation Center contains the names of 494 advanced degree scientists, 154 other scientists (including graduate students), and 167 foreign scientists. We conclude, therefore, that the interest of U. S. scientists is strong, and that our present facility will be inadequate to meet the requirements of users who want to utilize synchrotron radiation for their research problems in the near future.

An estimation of the growth potential in the utilization of synchrotron radiation for research and technological purposes is a difficult task because the impact of synchrotron radiation on many areas of research is just beginning to be felt, and it is difficult to judge with certainty how a given field will react to new capabilities at its disposal. We have been guided in this evaluation, however, by asking the question of whether or not the capabilities a synchrotron radiation source offers the scientist because of its properties such as intensity, tunability of energy, time structure, vacuum, etc. will permit experiments not possible previously. We then asked what body or group of scientists would be affected by the opportunity to do these experiments. In the areas of the life sciences, material sciences, photochemistry, and technological applications, the number becomes quite large. An important scaling factor, however, is how many of this group can be



SRC PUBLICATIONS (REFEREED JOURNALS)
45
40
35
30
25
20
15
10
5
INCOMPLETE LISTING
10/'76
PUBLICATIONS LISTED
BY YEAR OF
APPEARANCE
69
70
71
72
73
74
75
76
77
78
CALENDAR YEAR

identified as being likely to devote a significant fraction of their time to making use of a national facility utilizing the available radiation. Finally, of this smaller group of essentially full-time users, we asked how many stations in the energy range up to 1 keV would be necessary to supply their needs. The scaling factors, which we believe to be conservative, we have chosen are a factor of 1/3 of the groups that we can identify now, and the number of needed stations as 1/4 of the number of these essentially full-time equivalent users.

In the vuv/sxr areas we identify a group of life scientists who work at longer wavelengths and who employ photoabsorption and fast fluorescence techniques to characterize biologically active compounds. This group may be significantly affected by the ability to do EXAFS at the carbon edge, ~285 eV, as well as with other atoms, which are important from a biological or biochemical viewpoint. We conservatively estimate 60-80 scientists in this group. In the research areas involved with the characterization of materials by absorption, reflection, and photoemission, we predict a potential user group of 500-600. In support of the growth in the size of this group, we note, that under the titles "Electron Spectroscopy I. Ultraviolet Photo-excitation and Electron Spectroscopy II. X-ray Photoexcitation," the Fundamental Reviews compiled every two years by Analytical Chemistry list 315 papers in 1972 review, 760 in the 1974 review, and 923 in 1976. (The reviews in 1974 and 1976 also included electron excitation, and these papers are excluded from the quoted numbers.) Most of the work cited in these reviews has been done with line source excitation and without extreme care to avoid surface contamination.

In the molecular excitation and photochemistry areas, the potential for growth is very great because of the small numbers of chemists who are presently involved in experiments utilizing synchrotron radiation. Most chemical studies which employ vuv radiation are involved with questions of bonding, structure, energetics, or rearrangements. Some of this information has been provided from photoelectron spectroscopy. The size of the photo-chemical community impacted is difficult to estimate because it is possible that tunable lasers may provide part of the user requirements in this area of research. We do note, however, that a new society called the "Inter-American Photochemical Society" was recently formed as a consequence of discussions held at the VIII International Conference on Photochemistry at Edmonton, Canada, in August, 1975, and that the initial membership appears to be 400 or more. Estimates of the photochemical group are for 50-60 synchrotron radiation users by 1985.

In the technological applications area, we again find a strong correlation between the physical measurements and information on energy conversion devices such as solar cells where the energy band gap characterization becomes important, and catalytic conversion devices where knowledge of the chemistry and characteristics of the surfaces becomes important. New breakthroughs in this particular area may significantly alter all estimates of the use of synchrotron radiation, but a very conservative estimate would place 100-120 scientists in this category. The summary totals at this point, with the appropriate scaling factors discussed earlier, yield an estimate of 67-72 vuv/sxr stations.

In addition to these estimates, we expect that a facility with a research staff and experimental chambers designed to work with a variety of samples may impact a considerably larger group with scientific and technological problems that could be studied but no equipment to bring to bear on these particular problems. At this facility we would provide 2-3 vuv/sxr stations for use in this manner. This final addition brings the totals to that predicted earlier.

E. Users' Requirements of a National Synchrotron Radiation Facility

In addition to the universal goal of high intensity in the desired spectral region, all users of synchrotron radiation share at least some of the following general requirements: high brightness (small source cross section), continuous range of wavelengths, polarized photons, collimation, freedom from higher order overlap, low stray light, and a well defined time structure. All users look for a highly dependable, stable, intense source which is available 50 weeks per year.

Since demand for beam time is very high and because increasingly complex experiments will require increasingly large amounts of beam time, the facility should provide the maximum number of beam ports, each tailored as closely as is practical to the user's requirements. Indeed, the number of beam ports must exceed the expected average number of users, because only then is it possible for the facility to maintain the necessary flexibility to respond to variations in user demand.

A source suitable for vuv/sxr work should provide intense radiation up to the hard x-ray threshold (3 keV) without significant hard x-ray contamination. The problems of spectral purity are as severe in the vuv/sxr range as in the hard x-ray range (higher order radiation can be an extremely severe problem in this region where efficient filters and energy sensitive detectors are not available). There are additional considerations that are unique to vuv/sxr research.

In the vuv/sxr portion of the spectrum, wavelength selection is done with gratings, and optical elements are grazing to near normal incidence mirrors. If the incident power density is sufficiently small, efficient, relatively inexpensive polished quartz mirrors and conventional replica gratings may be used. If the mirror can be positioned close to the source, large solid angles of beam can be collected and directed to an experiment. It is desirable to eliminate high energy radiation from these beam lines to decrease the damage to optical elements and to eliminate the personal radiation hazard. Indeed, in this portion of the spectrum, it is very important to maintain personal access to all parts of the experiment and the preceding beam line so that the visual portion of the spectrum may be used for alignment, and so that the experiment may be operated "hands-on" to maximize the productivity and minimize the expense. Allowing beam lines free of high energy contamination and arranging for total personal access, however, must not be at the expense of personal safety or the performance of the source.

In the vuv/sxr region it must be possible to accommodate ultrahigh vacuum sample chambers, since it is necessary to avoid contamination of the sample surface in many experiments. The difficulty of constructing windows of any practical value for vacuum separation means that, in general, the experiment, monochromator, beam line, and the source must operate in a common ultrahigh vacuum. On the other hand, in experiments conducted with samples in the gas phase sample chambers typically operate at pressures orders of magnitude above those in the storage ring and the other experiments connected to the ring. Further, often times the samples that are of the greatest scientific and/or technological interest can create unacceptable contamination in the storage ring, the monochromators and in ultrahigh vacuum sample chambers which, of a necessity, share the common vacuum system. Thus differential pumping on beam lines to protect the investigators from each other and to protect the storage ring against all eventualities is a matter of extreme importance. The adequacy of these measures will determine the range of investigations that can be carried out at the facility.

The operation of storage rings as national synchrotron radiation facilities implies a significant amount of experimental support. The unique properties of synchrotron radiation that make it such a valuable source also introduce unique problems in designing and constructing beam lines, monochromators, and experiments to use the source to greatest advantage. Therefore, as is currently done at Wisconsin, the facility must be prepared to design, construct, and maintain the beam lines and optical elements up to the output of the monochromator. However, the management of experimental chambers for general use involves different considerations. Currently, responsibilities for experimental chambers at the Wisconsin Synchrotron Radiation Center fall into three categories:

a) An individual user group supplying the necessary chamber and associated electronics and support equipment.

b) Collaboration, particularly for a new group, with an existing experienced group.

c) Complete experimental equipment provided and maintained by the facility and used in collaboration with the in-house group.

All three approaches to experiments work well and each has its advantages. If a national facility is to be available to a maximum number of new users, categories b) and c) are very important. Experiments in the vuv tend to require a variety of individually designed sample chambers so that one would expect a) to continue to be important and it should continue to be possible to adapt with a minimum of effort, experimental equipment that a group uses in its home laboratory.

A level of support facilities beyond those required for maintenance of the machine and beam lines will be required for maximum efficiency. An easily-accessed data reduction computer should be available for preliminary analysis of data even if the user does final data reduction at his home institution. The wide variety of experiments that will be performed will require basic laboratory support facilities in chemistry and biology for sample preparation and characterization. The inevitable difficulties encountered in experimental science require readily available electronic and mechanical engineering and shop support facilities.

Finally, since users, particularly those working in the vuv/sxr region, will spend substantial periods of time at the facility, low cost, comfortable housing should also be available, on site. The existence of such housing will do much to increase user efficiency and to decrease research costs.

F. Characteristics of Synchrotron Radiation of Importance in the Design of a Storage Ring Source

Electrons experiencing centripetal acceleration in the magnetic guide fields of a circular accelerator radiate electromagnetic energy as was predicted by Maxwell. In their own frame of reference, they emit a characteristic Larmor radiation pattern. For highly relativistic electrons, this pattern becomes strongly distorted in the forward direction as viewed by an observer in the laboratory frame. Thus, if one looks in the orbital plane in the direction opposite to the electron's motion and tangent to the orbit, the electron will be seen as a bright point of light. A narrow cone or radiation sweeps past the observer just as the electron reaches the tangent point being viewed. The fundamental orbit frequency and many higher harmonics are present in the light observed. In fact, harmonics of the orbit revolution frequency up to the order of γ^3 are present. However, the spectrum, while in principle composed of discrete harmonics of the electron orbit frequency, actually appears to be a continuum even for a single electron because the spacing of the harmonics is so close. For a number of electrons, due to the natural spread in orbit frequencies resulting from the energy spread of the beam and small amplitude oscillations of the electrons about the central orbit, the spectrum is smeared and thus truly becomes a continuum.

The spectrum is characterized by a strong peak at the shorter wavelengths and a relatively slow fall-off towards the longer wavelengths. The wavelength position of the peak is proportional to $1/\gamma^3$, thus the short wavelength capabilities of a particular accelerator as a source of synchrotron radiation is an extremely strong function of the accelerator energy. At wavelengths close to the spectral peak, which is very nearly the same as λ_c, the so-called critical wavelength given in angstroms by $\lambda_c = 5.59\ R/E^3$ where R is the local radius of curvature of the electron path, the radiation from the circulating electron is contained within a narrow vertical angle given approximately by $\sim 1/\gamma$. This is a natural result of the transformation between the electron rest frame and the laboratory frame of reference. Due to this strong vertical collimation, the light from a circulating beam of electrons is unlike that from any other source: While photons are emitted over the full 2π of the orbit, they are emitted in a rather flat pancake vertically. Further, again as a natural result of the transformation, the light is strongly polarized in the orbit plane. In fact, on the orbit plane, the light is 100% polarized and elsewhere, above and below the orbit plane, the light is elliptically polarized. Taken together, these properties are responsible for the great utility of synchrotron radiation in many and diverse scientific investigations.

The spectral properties of synchrotron radiation were first calculated in detail by Schwinger and later verified experimentally both in the United States and the Soviet Union in the years immediately following the Second World War. Formulae for calculating these spectral properties are now well-known and will not be reproduced here. However, one of these expressions has important implications to the design of any modern synchrotron radiation facility:

$$\frac{dI}{d\lambda} \quad \frac{\text{photons}}{\text{sec } \text{Å mrad}} = 9.35 \times 10^{13} \text{ J (ma) } \frac{[R(m)]^{1/3}}{[\lambda\ (\text{Å})]^{4/3}} .$$

In this expression, it will be noticed that the photon flux is independent of the electron energy and varies as only a weak power of the local radius of curvature of the electron orbit. Thus, the synchrotron radiation spectra from electron accelerators of quite different energies are remarkably similar at wavelengths far from λ_c. This fact, plus geometrical considerations to be discussed in a later section, explains why it is possible for the relatively low energy (240 MeV) machine at the Synchrotron Radiation Center of The University of Wisconsin, Tantalus I, to compete with and surpass the performance of machines of much higher energy such as SPEAR or DORIS in the photon energy range below 50 eV. This performance level is achieved without the complications arising from hard x-ray contamination of the photon beams that are characteristic of high energy machines. Further, because the degree of elliptical polarization of "off orbit plane" radiation is proportional to λ/λ_c, the total polarization of the synchrotron radiation will be better at a given wavelength the closer it is to λ_c. These considerations give support to our contention that a synchrotron radiation source for vuv and soft x-ray research should have the largest value of λ_c consistent with the needs of the research program.

In practical sources of synchrotron radiation, that is to say in electron storage rings and synchrotrons, the electron beam has a significant cross section which is characterized by the parameters σ_x and σ_y. In addition, the cross section of the electron beam varies as a function of position along the orbit. Thus, along with σ_x and σ_y, the additional parameters $\sigma_{x'}$ and $\sigma_{y'}$ which are the derivatives of the beam cross section with respect to circumferential position must be taken into consideration in comparing synchrotron radiation sources. If $\sigma_{y'}$ is larger than γ^{-1}, the brightness of the electron beam as a source will be unnecessarily degraded. Therefore, it is of great importance to make σ_x and σ_y and their derivatives as small as possible at the source points in machines designed to be synchrotron radiation sources in order that the highest brightness be achieved.

The energy that is radiated by the electrons must be restored or the electrons will be rapidly lost from the machine. This is accomplished by applying a radio frequency to the electrons as they circulate by means of a suitably designed resonant structure. The dynamics of the interaction of the electrons with the accelerating system result in the electrons being bunched. Thus at a particular point on the circumference of the machine the synchrotron radiation occurs in discrete "flashes". The circumferential length of these bunches, which determines the time duration of the flashes, is designated σ_s. This is a machine property of importance to investigators concerned with time resolved spectroscopies.

These parameters σ_x, σ_y, $\sigma_{x'}$, $\sigma_{y'}$, and σ_s are determined by the design of the machine and they exert a strong influence on the research utility of the synchrotron radiation source. Thus the design of a modern source is best carried out by accelerator specialists with an appreciation for the research aims of the investigators.

III. Description of the Expanded Facility

A. Brief Description of Aladdin and Super Aladdin

To meet the needs and criteria established in the previous section, we propose to construct an intermediate (750 MeV) energy storage ring, which we have named Aladdin, the design features of which reflect both the experience gained by us in operating an extremely successful synchrotron radiation research facility for the past eight years and extensive input by our user group. Aladdin, as designed, will provide two orders of magnitude greater usable flux in the spectral range now being investigated with Tantalus I as well as a much increased spectral range. A modification of Aladdin, to be carried out after "running in", can increase the source brightness of the proposed machine, and therefore the usable photon flux, by a factor of as much as seven. The modified machine will be called Super Aladdin. In this section we give an overall description of these machines and their expected performances. More detailed descriptions of the machines and their injector are given in the next section.

With Tantalus I, because of the high energy "cut-off", there is essentially no synchrotron radiation beyond 40 Å (300 eV). The proposed machine, Aladdin, extends the source spectrum to 4 Å (3 keV), with much greater intensity in the soft x-ray range beyond 100 Å (above 125 eV). However, the high energy "cut-off" of the Aladdin synchrotron radiation spectrum allows personnel close access to the ring, thus conventional vuv/sxr optical elements can be located within 1.5 m of a photon source.

In order to provide maximum space for the photon extraction pipes, Aladdin is designed with asymmetric lattice units. Each basic unit consists of two quadrupoles, one "C" type bending magnet, and an empty space, in that order. Aladdin has twelve units. Approximately one-half of all synchrotron radiation generated in the bending magnets can be made available to experimenters.

Increased source brightness has been a continuing demand of our synchrotron radiation users. Maximum source brightness in storage rings can be realized by high circulating beam current and by small source size. The storage ring will be capable of 1 ampere average circulating beam current. By using moderately high quadrupole excitations, the beam envelope can be minimized in the bending magnets and hence the source sizes can be kept very small. The size (4σ) of the photon source in Aladdin will be about 1.56 mm in the plane of the orbit and 0.22 mm in the vertical plane. For Super Aladdin, the source size will be 0.68 mm by .068 mm. Since the unit cells are identical, every bending magnet of Aladdin (and Super Aladdin) will have the same source characteristics.

Features normally expected of storage ring operation (excellent vacuum and source stability) will not be compromised in this ring. Source stability in position and intensity is an especially important requirement of the experimenters. Proper magnet construction and alignment will guarantee that the equilibrium orbit is independent of energy. Given this, source position is then locked to the crystal controlled RF system with a stability better than one part in 10^6. Long term energy stability depends on magnetic guide field regulation and will be better than 0.01%. Short term energy stability is 50 times better than this because of the guide field magnet inductances.

Injection into Aladdin will be essentially the same as in the present operation of Tantalus I, though computer control will greatly facilitate and improve the operation. The computer will act primarily as a monitor for all machine functions and as a link between the operators and the machine. An equally important task of the computer will be that of retaining and recalling on command tables of parameters for specific operating modes of the storage ring. These may then be set, or altered, as the need may be at the command of the operators. Under stored beam conditions the computer will be in the monitor mode and will thus have unused capacity which can be made available to the investigators for data storage and manipulation and for program development. While the development of computer aided data acquisition services does not form a part of this proposal, a discussion of a possible approach to this problem is given in Appendix III. In addition, computer control of injection will allow storing any number of bunches, from one up to the harmonic number of the RF system. For Aladdin, this means up to 200 nsec between beam pulses. In the absence of bunch lengthening, "natural" bunch length of approximately 0.5 nsec (4σ) is expected. Detailed parameters for Aladdin and Super Aladdin are presented in Tables I, II, and III.

Figure 1 shows the synchrotron radiation fluxes in a 0.1% bandwidth for Tantalus I, Aladdin, and Aladdin with a possible 5.0 T transverse wiggler mounted in a long straight section. The order of magnitude increase in cutoff energy between Aladdin and Tantalus I is clearly shown by the curves in this figure. With the 1 ampere electron beams expected in Aladdin and tens of milliradians acceptable by some instruments, about four orders of magnitude increase in fluxes over these 1 mA and 1 mrad fluxes will be available for some experiments.

FLUX IN PHOTONS/Sec/mA/mrad IN 0.1% BANDWITH FROM TANTALUS I, ALADDIN & 5.0T WIGGLER INSTALLED ON ALADDIN

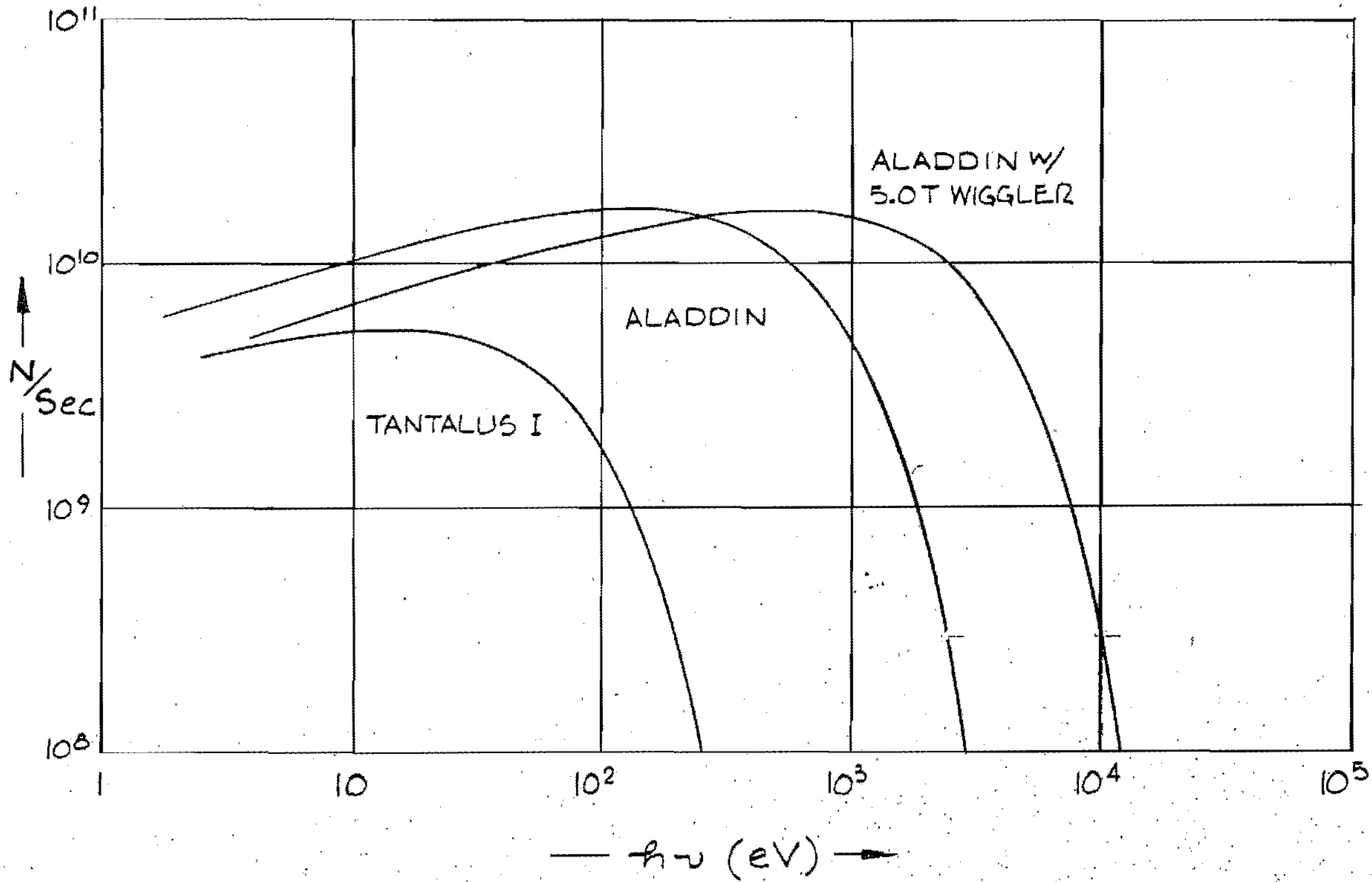


Figure 1

Table I. Synchrotron Radiation Parameters

	Aladdin		Super Aladdin	
Energy	750	MeV	750	MeV
Revolution Frequency	4.34	MHz	4.34	MHz
Period	0.23	μsec	0.23	μsec
Bending Radius	2.08	m	2.08	m
Critical Wavelength	27.6	Å (450 eV)	27.6	Å (450 eV)
Source Sizes (4 σ)				
Radial	1.56	mm	0.68	mm
Vertical	0.22	mm	0.068	mm
Bunch Lengths (4σ)	0.57	nsec	0.27	nsec
Emittances (10% coupling)				
Radial	0.38	π mm mrad	.063	π mm mrad
Vertical	0.0038	π mm mrad	.00063	π mm mrad
Quantum Lifetime	> 24	hrs	> 24	hrs
Touschek Lifetime	> 8	hrs	> 8	hrs
Peak Circulating Current	1	A	1	A

Table II. Aladdin

General		
Energy	750	MeV
Revolution Frequency	4.34	MHz
Critical Wavelength	27.6	Å
Damping Times		
Radial	21.8	msec
Vertical	22.3	msec
Energy	11.3	msec
RF System		
Harmonic	13	
Number of Cavities	1	
Max. Volts Per Turn	250	kV
RF Power to Beam (1 A)	13.4	kW
Vacuum System		
Construction	Stainless Steel, Bakeable	
Pressure	10^{-9} to 10^{-10} Torr	
Corrections		
Sextupoles and Higher Order Multipole Magnets	24	

Injection

Type – Multiturn using shorted transmission line inflector with two pulsed dipoles.

Source – 100 MeV Racetrack Microtron with 5 cell accelerating & focusing structures. Two 180° bending & focusing end magnets.

Magnet		
Betatron Tunes		
Radial	~ 5.15	
Vertical	~ 5.15	
Momentum Compaction	0.051	
Basic Unit		
Focusing Order	FDBO	
Bending Magnet		
Radius	2.08	m
Field Index	0	
Edge Angles	15°	
Quadrupoles		
Max. Grad.	1.6	kG/cm
Phase Advance		
Radial	94.5°	
Vertical	124.5°	
Long Straight		
Focusing Order	FDFOFDF	
Central Drift Space	4	m
Quadrupoles		
Max. Grad.	1.6	kG/cm
Phase Advance		
Radial	360°	
Vertical	180°	

Tables IV and V compare some of the relevant synchrotron radiation parameters for the three storage rings Tantalus I, Aladdin, and Super Aladdin. In column 8 of Table V the total vertical angle ψ_T is given by $\psi_T^2 = \psi^2 + (3.2\ \sigma_{y'})^2$ where ψ is the synchrotron radiation vertical angle for 90% of the beam. In column 13 of Table V the flux available to specified monochromators is tabulated on the basis of geometrical acceptance alone. A 100 mA beam is assumed, and D is the distance from the source point to the valve, as defined in Table IV. Optical efficiencies of crystals, gratings or mirrors are not included. The values for 3 Å through 10 Å assume a crystal monochromator with $\pm 10^{-5}$ radian vertical angular acceptance and 2×10^{-4} radian horizontal angular acceptance. A $\Delta E/E$ of 5×10^{-5} is assumed. For $\lambda = 30$ and 100 Å, a representative grazing incidence monochromator with $\Delta E/E = .001$ is assumed. For $\lambda = 300$ and 1000, a representative Seya-Namioka monochromator with $\Delta E/E = .001$ is assumed. Entries for the 10 to 3 Å range given in this column could be increased greatly through the use of cylindrical crystal and mirror optical systems.

Table IV. Comparison of Wavelength Independent Quantities for Tantalus I, Aladdin, Aladdin with a 5T Wiggler, Super Aladdin, and Tantalus 2.5 (10% coupling)

Source Machine	E (GeV)	ρ (m)	λ_{oc} (A)	4σ Beam Size (mm) H	4σ Beam Size (mm) V	$\sigma_{x'}$ (mrad)	$\sigma_{y'}$ (mrad)	Source to Valve Distance D (m)	Angle Passed Through 1-1/4" I. D. Valve at D (mrad)	First Mirror Type
Tantalus I	0.24	.635	257	2.5	0.23	.44	.048	0.5	64	Glass
Aladdin (ν = 5.15)	0.75	2.08	27.6	1.56	0.22	.22	.017	0.75	42	Glass
Aladdin with 5T Wiggler	0.75	0.50	6.63	3.43	0.2	.18	.013	8.00	4	Cooled Metal
Super Aladdin	0.75	2.08	27.6	0.68	.068	.21	.0078	.75	42	Glass
Tantalus 2.5	2.5	6.95	2.49	1.0	0.27	.20	.022	1.5	20	Cooled Metal

Table V. Comparison of Wavelength Dependent Quantities for Tantalus I, Aladdin, Super Aladdin, Aladdin with a 5T Wiggler, and Tantalus 2.5

1	2	3	4	5	6	7	8	9	10	11	12	13
λ (Å)	hν (eV)	Source Machine	Flux in 1 mrad for ΔE/E = .001 I = 100 mA	Second Order Content (λ/2)/λ	Third Order Content (λ/3)/λ	90% Sync. Rad. Vertical Angle (mrad)	90% Total Vertical Angle ψ_T (mrad)	Vertical Emittance for $4\sigma_y$ (mm mrad)	Polarization for 90% of Beam	Fraction of Beam for P = 90%	Flux through 1-1/4" I.D. Valve at D ΔE/E = .001	Flux Available to the Specified Monochromator
0.3	41.3K	Tantalus 2.5	6.03 E09	< .01	<.01	0.14	.16	.043	.95	1.00	1.27 E11	1.1 E07
		Aladdin + Wiggler	8.67 E09	< .01	<.01	0.52	.53	.106	.95	1.00	3.47 E10	4.4 E06
1.0	12.4K	Tantalus 2.5	1.23 E12	.10	.011	0.25	.26	.070	.88	.84	2.59 E13	1.2 E09
3.0	4.13K	Aladdin (S. A.)	7.60 E08	< .01	<.01	0.43	.44	.097 (.03)	.96	1.00	3.19 E10	4.6 E05
		Aladdin + Wiggler	4.67 E11	.14	.02	0.88	.89	.18	.87	.99	1.87 E12	1.3 E08
		Tantalus 2.5	4.48 E12	.56	.28	0.42	.43	.12	.79	.58	9.41 E13	2.6 E09
10	1.24K	Aladdin (S. A.)	2.92 E11	.083	<.01	0.78	.78	.17 (.05)	.89	.87	1.23 E13	8.9 E07
		Aladdin + Wiggler	1.48 E12	.65	.38	1.52	1.52	.30	.76	.53	5.92 E12	2.2 E08
		Tantalus 2.5	5.62 E12	.98	.85	0.67	.67	.18	.68	.41	1.18 E14	1.7 E09
		Tantalus I	4.48 E08	< .01	<.01	1.4	1.4	.32	.96	1.00	2.87 E10	5.6 E08
30	413	Aladdin (S. A.)	1.27 E12	.48	.23	1.3	1.3	.29 (.09)	.80	.57	5.32 E13	4.5 E12
		Aladdin + Wiggler	1.68 E12	.98	.88	2.4	2.4	.48	.67	.39	6.72 E12	-------
		Tantalus 2.5	4.84 E12	1.15	1.19	1.0	1.0	.27	.62	.35	1.02 E14	1.9 E13
		Tantalus I	1.10 E11	.10	<.01	2.5	2.5	.58	.90	.88	7.06 E12	2.6 E11
100	124	Aladdin (S. A.)	1.69 E12	.92	.78	2.2	2.2	.48 (.15)	.69	.42	7.10 E13	1.2 E13
		Aladdin + Wiggler	1.38 E12	1.14	1.20	3.7	3.7	.74	.61	.32	5.52 E12	-------
		Tantalus 2.5	3.58 E12	1.21	1.35	1.5	1.5	.41	.58	.29	7.51 E13	3.1 E13
		Tantalus I	4.21 E11	.54	.26	4.2	4.2	.97	.81	.62	2.70 E13	4.6 E12
300	41.3	Aladdin (S. A.)	1.48 E12	1.11	1.07	3.2	3.2	.70 (.22)	.62	.35	6.23 E13	3.2 E13
		Aladdin + Wiggler	1.04 E12	1.22	1.35	5.4	5.4	1.08	.58	.28	4.16 E12	--------
		Tantalus 2.5	2.58 E12	1.23	1.40	2.2	2.2	.59	.56	.28	5.42 E13	6.2 E13
		Tantalus I	5.41 E11	.94	.81	6.8	6.8	1.6	.70	.42	3.46 E13	6.9 E12
1000	12.4	Aladdin (S. A.)	1.11 E12	1.20	1.33	5.0	5.0	1.1 (.34)	.58	.30	4.64 E13	2.4 E13
		Aladdin + Wiggler	7.22 E11	1.22	1.37	8.0	8.0	1.6	.56	.28	2.89 E12	--------
		Tantalus 2.5	1.76 E12	1.27	1.44	3.4	3.4	.92	.55	.25	3.70 E13	4.3 E13

Items in parentheses in Columns 3 and 9 refer to Super Aladdin.

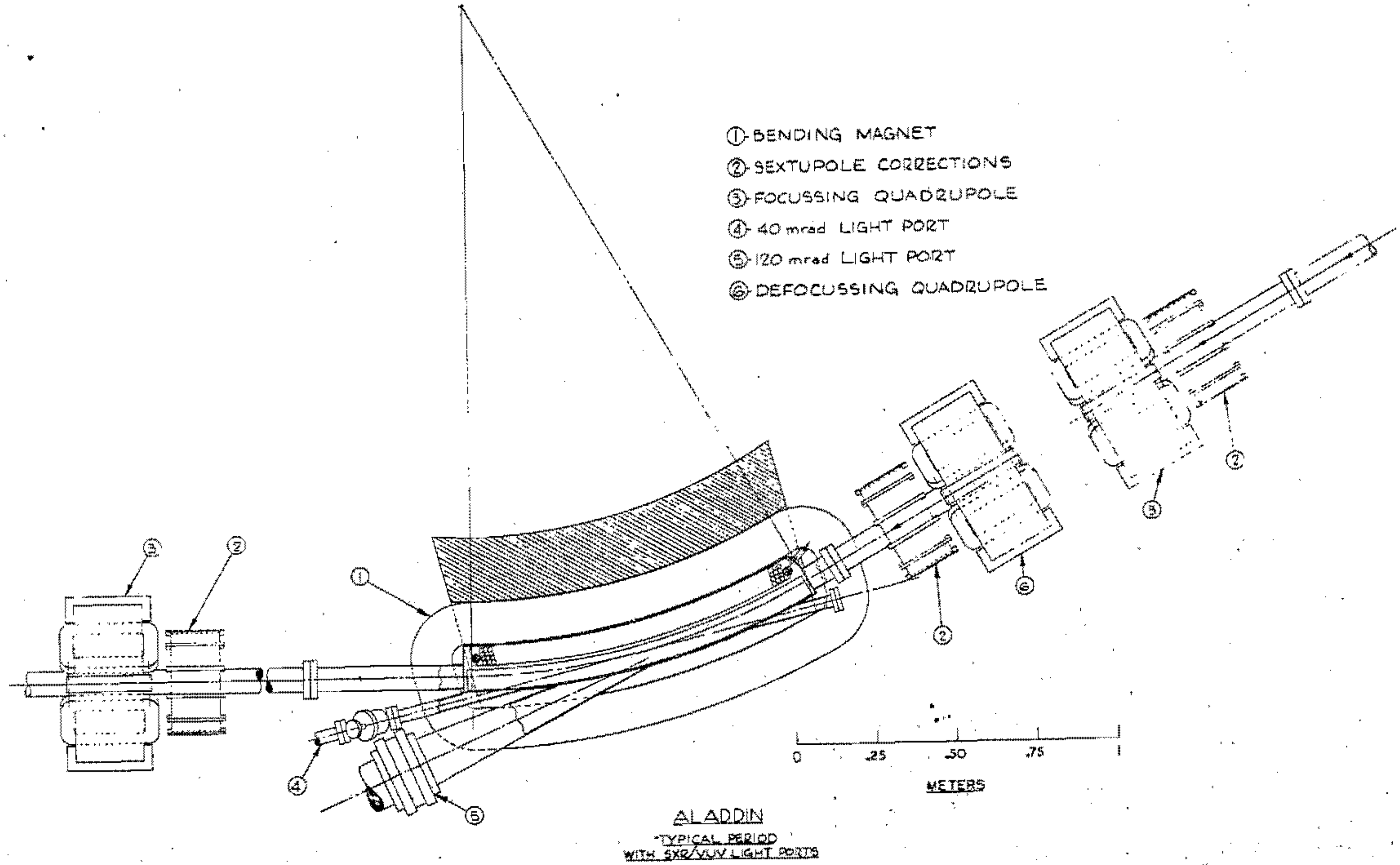
B. Detailed Description of the Aladdin/Super Aladdin System

The lattice structure of Aladdin consists of twelve unit cells and two long straight sections. Each unit cell is comprised of a multi-pole correction magnet, a radially focusing quadrupole, a vertically focusing quadrupole, a second multipole correction magnet and a bending magnet, in that order. The unit cell geometry is asymmetric, i.e. the focusing elements are not centered between bending magnets, in order to maximize access to the vacuum chamber in the bending magnets for the installation of light ports. A layout of the Aladdin unit cell is shown in Fig. 2.

The design and construction of the quadrupoles and bending magnets which are utilized in the Aladdin lattice is essentially the same as was employed in Tantalus I but with some modifications that have been developed as a result of experience gained during the eight years that this machine has been operating. As with Tantalus I, the magnets and quadrupoles will be laminated, a construction practice that has been adopted in all recent electron storage ring designs. However, edge corrections in the bending magnets to maintain constant magnetic length, and therefore orbit position, over the full range of magnet excitation which were not included in the Tantalus I magnets will be employed on the Aladdin magnets.

The unit cell design chosen for Aladdin has the property that the electron beam cross sectional dimensions are at near minima in the bending magnet. This is indicated by the plots of β and η functions which are shown in Fig. 3. Since the twelve unit cells are identical, every photon source will have the same optical properties. Thus optical systems matched to one port may be moved to another without loss of performance. Experience gained in supporting the research program at Tantalus I for the past eight years has convinced us of the value of this machine property in reacting with minimal lost time to the demands imposed by the rapidly developing application of synchrotron radiation.

As is to be expected, the electron beam envelope functions change in the long straight sections. However, as is shown in Fig. 4, the major change is in the β_x (horizontal) function, thus the increase in beam cross section in the long straight sections will have minimal effect on the output flux of a monochromator utilizing the synchrotron radiation from a transverse wiggler mounted in a long straight section. The β and η functions as shown indicate that the electron trajectories will be nearly parallel in the long staight sections as is required to obtain the highest degree of monochromaticity from a helical wiggler. If necessary, the excitation of the long straight section quadrupoles can be altered to produce very small values of β thus creating a "low β insertion" for the installation of a very high brightness transverse wiggler. In this mode of operation the beam cross sectional area in the long straight sections would be reduced by a factor of about 5 over that in the bending magnets.



1 BENDING MAGNET
2 SEXTUPOLE CORRECTIONS
3 FOCUSSING QUADRUPOLE
4 40 mrad LIGHT PORT
5 120 mrad LIGHT PORT
6 DEFOCUSSING QUADRUPOLE
0 .25 .50 .75 1
METERS
ALADDIN
TYPICAL PERIOD
WITH SXR/VUV LIGHT PORTS

Figure 2

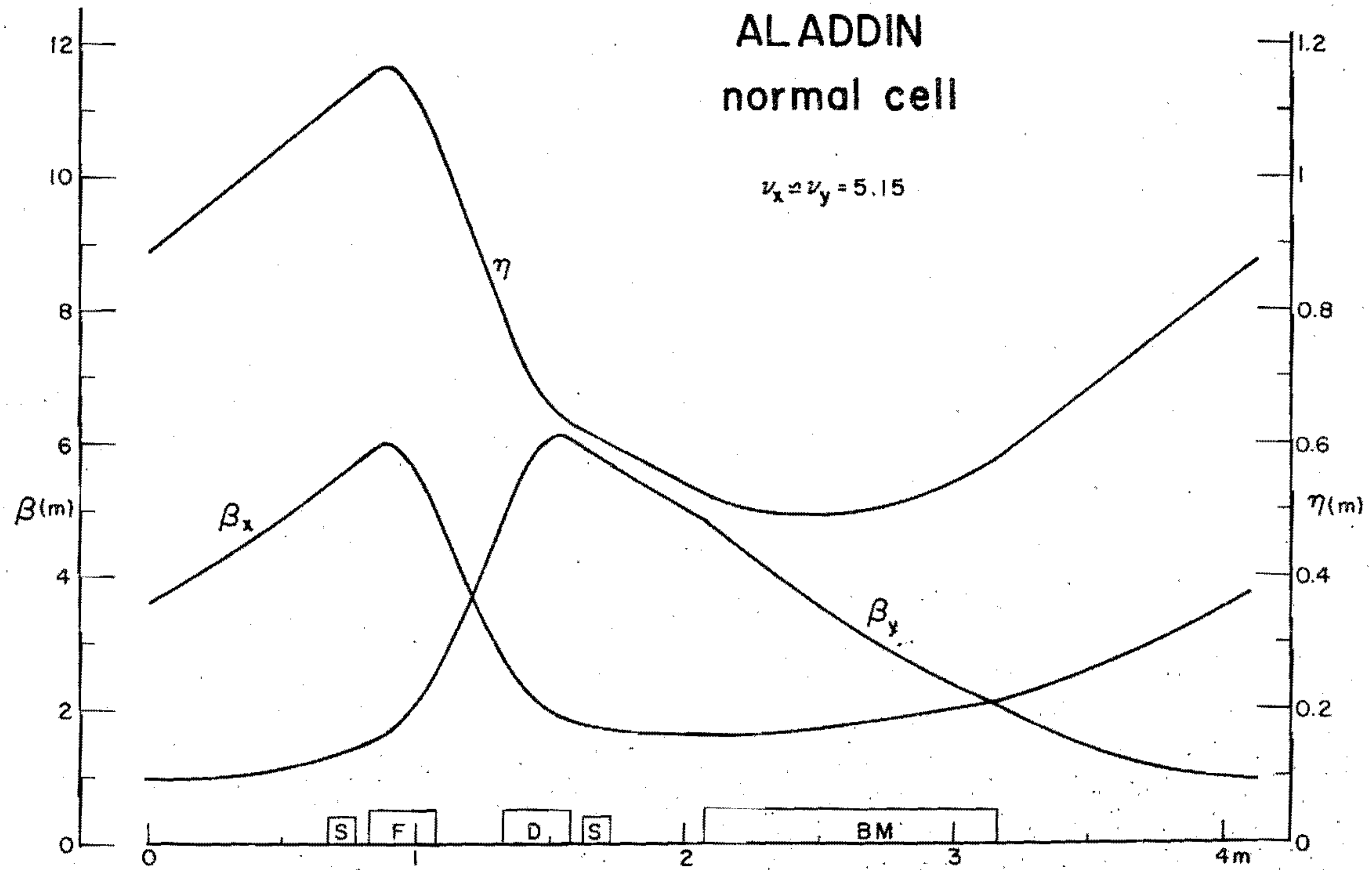

ALADDIN
normal cell
$\nu_x \simeq \nu_y = 5.15$
η
β_x
β_y
β(m)
η(m)
12
10
8
6
4
2
0
1.2
1
0.8
0.6
0.4
0.2
0
S
F
D
S
BM
0
1
2
3
4m

Figure 3

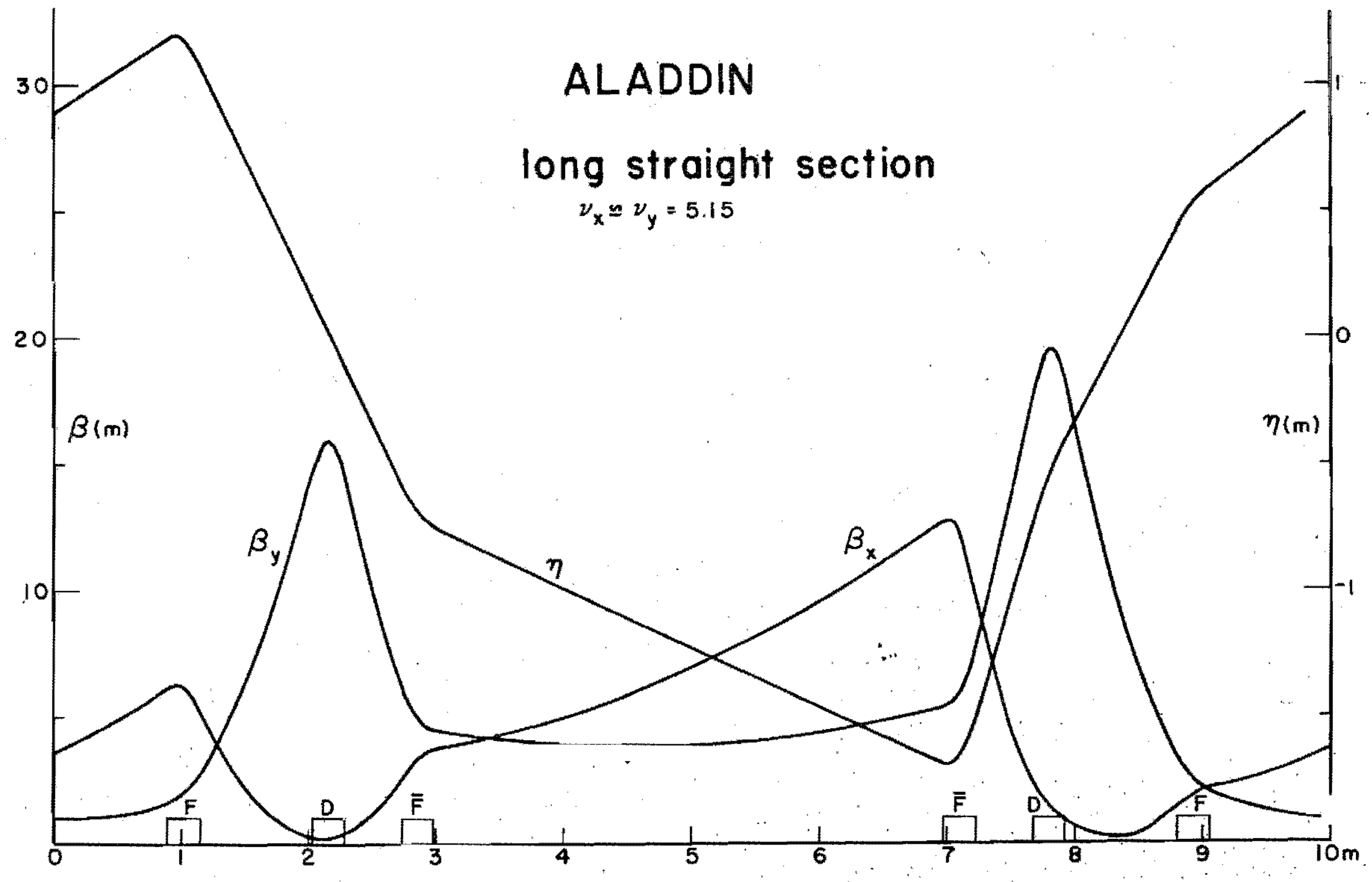

ALADDIN
long straight section
$\nu_x \cong \nu_y = 5.15$
β(m)
η(m)
β_y
β_x
η
F
D
F̄
F̄
D
F
30
20
10
0
1
2
3
4
5
6
7
8
9
10m
1
0
-1

Figure 4

An overall plan view of Aladdin is shown in Fig. 5. The injector machine will be mounted inside of the storage ring so that valuable experimental area outside of the ring will not be taken up by electron beam transfer systems, injector machine, radiation shielding, and ancillaries. However, storage ring power supplies, coolant circulating pumps and similarly acoustically noisy items will not be mounted in this area. While mounting as much of such equipment as possible within the ring is attractive from the economics of the construction of the ring, the creation of a low noise environment for the investigators is, in our judgment, far more important.

The Aladdin vacuum system design and construction is based on the vacuum system developed for and now installed in Tantalus I. This system is constructed of stainless steel and employs internal sputter ion pumps mounted in the bending magnet fringe field region. Currently, operating pressures in this system in the low 10^{-10} Torr range with 0.15 amps circulating are standard, thus we have considerable confidence in the design. The vacuum chamber will be of rectangular cross section in the bending magnets to accommodate the sputter ion pumps and circular in cross section in the short straight sections between normal cells. In the long straight sections, the cross section will also be circular but of increased diameter to accommodate the injection and fast beam dump extraction equipment to be installed there. Transitions between sections will be carefully designed so as to minimize the build-up of standing waves generated in the vacuum chamber by the intense electron beams. Mounted in every short straight section will be position sensitive electrodes and feedback electrodes for monitoring the operation of the storage ring and controlling coherent instabilities.

For the radio frequency accelerating system, an operating frequency of approximately 50 MHz has been chosen as a best compromise in that it makes possible a reasonably high shunt impedance accelerating cavity with a large degree of freedom from the high order deflecting modes that have been responsible for increased beam cross sections in other storage rings. This choice of frequency also allows us to use the very well developed gridded power tube available now rather than the still somewhat experimental klystrons that would be necessary for frequencies in the 200 to 500 MHz range. The required energy gain per turn in Aladdin operating at 750 MeV is 12.5 keV. With one ampere circulating, the radio frequency system must supply 12.5 kW to the electron beam plus power to make up for cavity losses. Operating with an overvoltage factor of ten for an acceptable Touschek lifetime, the total radio frequency demand will be less than 35 kW at maximum beam current. The cavity will be constructed of copper clad steel and will be evacuated. Provisions for servo tuning the cavity to compensate for beam induced currents will be included. Design details of the accelerating cavity are shown in Fig. 6 .

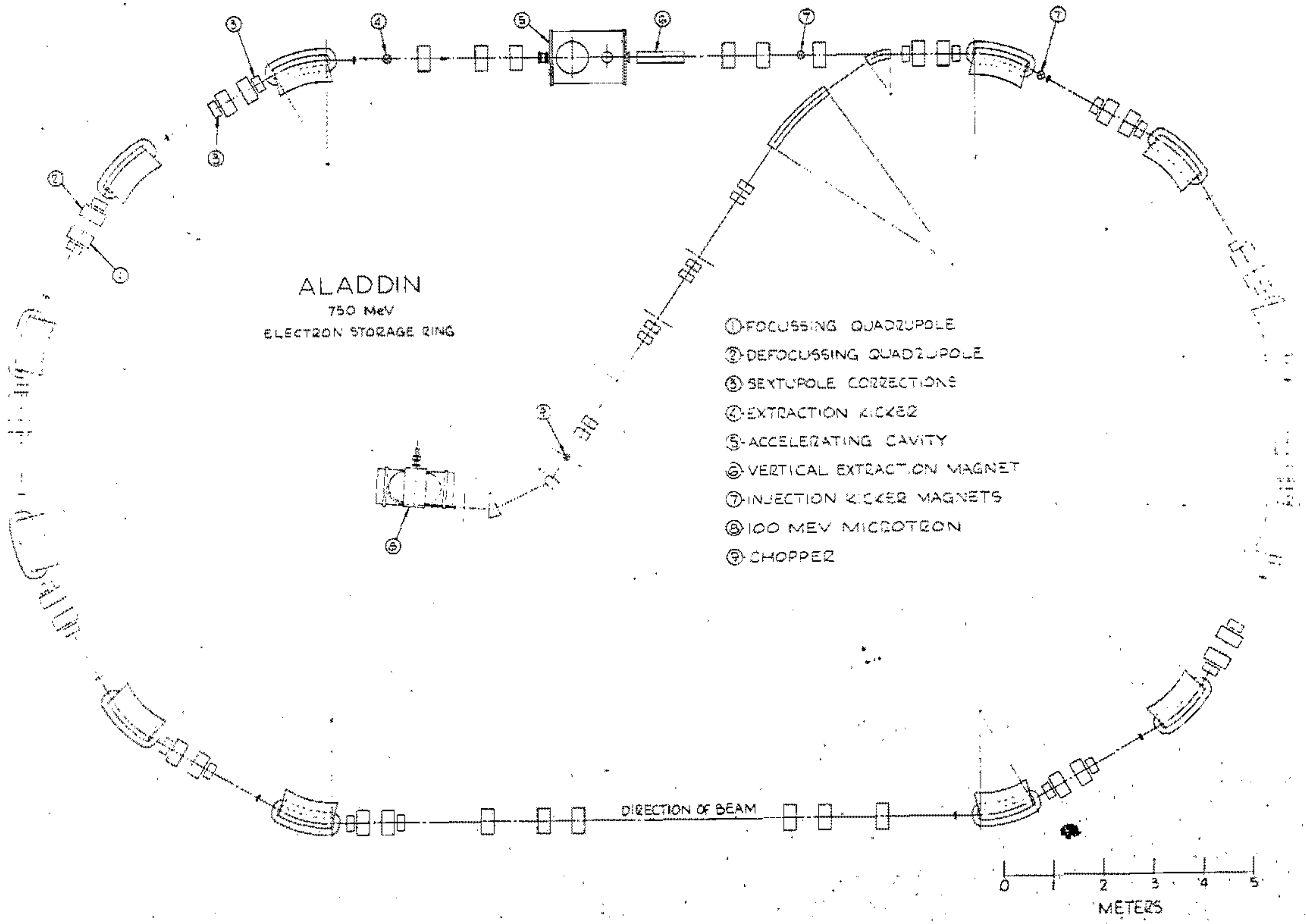

ALADDIN
750 MeV
ELECTRON STORAGE RING
① FOCUSSING QUADRUPOLE
② DEFOCUSSING QUADRUPOLE
③ SEXTUPOLE CORRECTIONS
④ EXTRACTION KICKER
⑤ ACCELERATING CAVITY
⑥ VERTICAL EXTRACTION MAGNET
⑦ INJECTION KICKER MAGNETS
⑧ 100 MEV MICROTRON
⑨ CHOPPER
DIRECTION OF BEAM
0
1
2
3
4
5
METERS

Figure 5

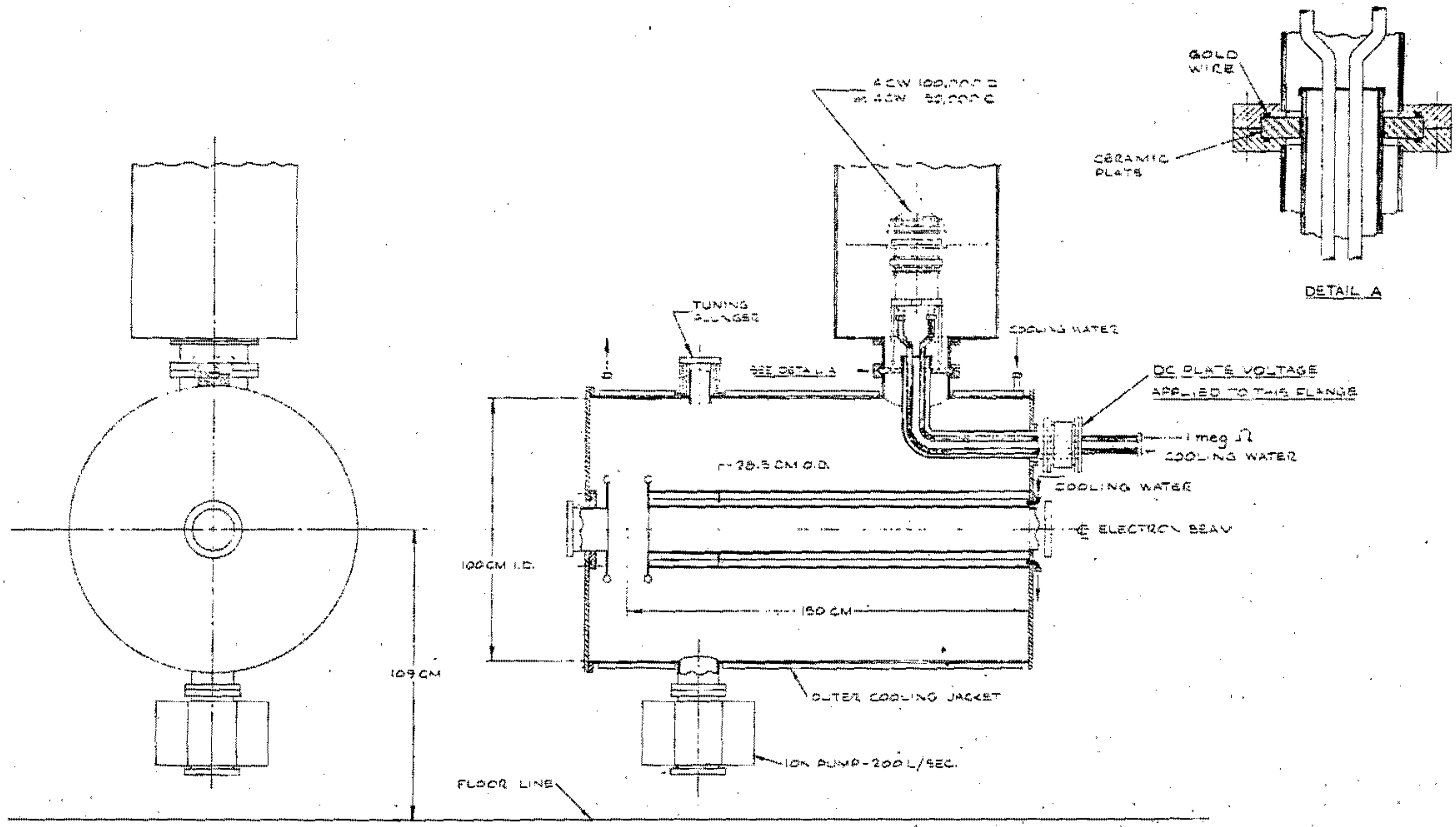

GOLD WIRE
CERAMIC PLATS
DETAIL A
TUNING PLUNGER
COOLING WATER
SEE DETAIL A
DC PLATE VOLTAGE APPLIED TO THIS FLANGE
1 meg Ω
COOLING WATER
COOLING WATER
ELECTRON BEAM
28.5 CM O.D.
100CM I.D.
150 CM
109 CM
OUTER COOLING JACKET
ION PUMP-200 L/SEC.
FLOOR LINE

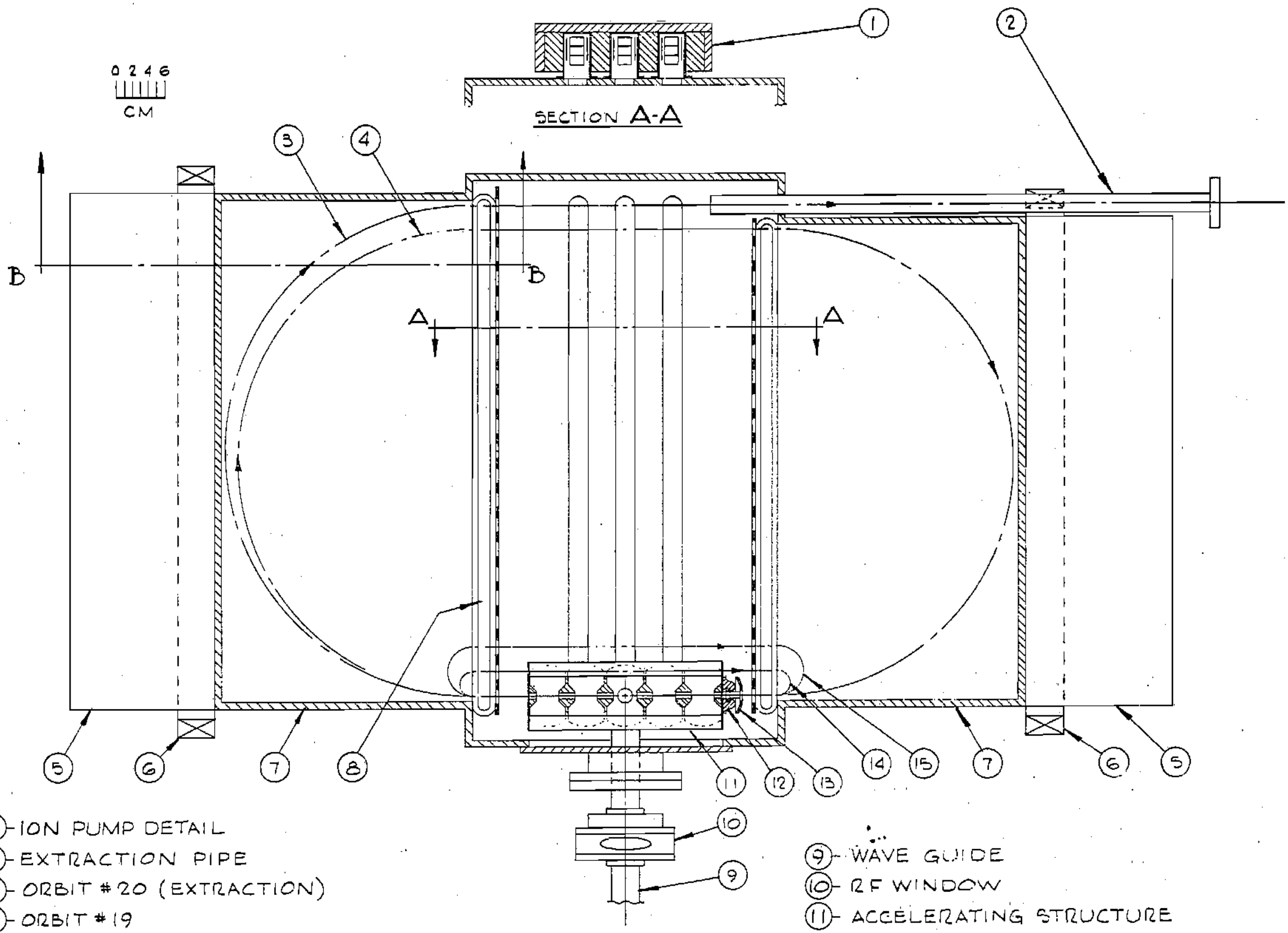
Figure 3

The injector accelerator for Aladdin will be a 100 MeV race track microtron. This machine is a development of the 44 MeV microtron designed and built by the Synchrotron Radiation Center operations group and which is now in service as the injector for Tantalus I. This microtron has the distinction of not only being the highest energy machine of this type ever to be built but also of being the first microtron designed and built in the United States that operated successfully. The 100 MeV microtron differs from the 44 MeV machine in that it is of the split sector design to allow the use of a multi-cell accelerating structure. As a consequence, the 100 MeV microtron operates at a much higher energy gain per turn than the 44 MeV microtron, and therefore requires only twenty orbits to achieve the design energy. This is to be compared with the thirty-four orbits required in the 44 MeV machine. Nevertheless, the principles of operation of the two machines are identical, thus even though the 100 MeV microtron will represent quite a step forward in the technology of small accelerators, there is little question of its successful operation. A list of principle design parameters of the 100 MeV microtron is given in Table VI. In Figs. 7 through 10 a plan view and drawings describing the major components of the machine appear.

Table VI. 100 MeV Microtron Parameters

Type	Split sector
Number of orbits	20
Magnetic field	~1.0 T
Accelerating radio frequency	3.0 MHz
Radio frequency power	6 MW
Radio frequency source	Magnetron type VMS1141
Accelerating structure	5 Cell standing wave π mode slot coupled
Energy gain per orbit	5.0 MeV
Beam current (pulse)	30 mA
Beam pulse length	2.5 sec
Principal operating parameters:	
ν	1
Ω	10

Upon extraction from the microtron, the electrons will pass through a beam transport system twelve meters long to the Aladdin injection plane. The beam transport system is shown in plan view in Fig. 5 and schematically with beam envelopes in Fig. 11. The first two bending magnets perform an achromatic bend and in conjunction with the first qudrupole doublet produce a double focus with zero energy dispersion at the beam aperture stop plane. The chopper will deflect the beam into the beam stop aperture in synchronism with the Aladdin radio frequency system. Thus, the only electrons to arrive at the injection plane will be those in the proper phase for radio frequency capture. This technique will not only reduce the energy disposition in Aladdin and, more importantly, the uncontrolled stray radiation during injection, but



(1)- ION PUMP DETAIL
(2)- EXTRACTION PIPE
(3)- ORBIT # 20 (EXTRACTION)
(4)- ORBIT # 19
(5)- BENDING MAGNET RETURN YOKE
(6)- COIL
(7)- VACUUM CHAMBER
(8)- ACTIVE FIELD CLAMP
(9)- WAVE GUIDE
(10)- RF WINDOW
(11)- ACCELERATING STRUCTURE
(12)- INJECTOR ANODE
(13)- INJECTOR CATHODE
(14)- INJECTION RETURN PATH
(15)- ORBIT # 2

MICROTRON PLAN VIEW

Figure 7

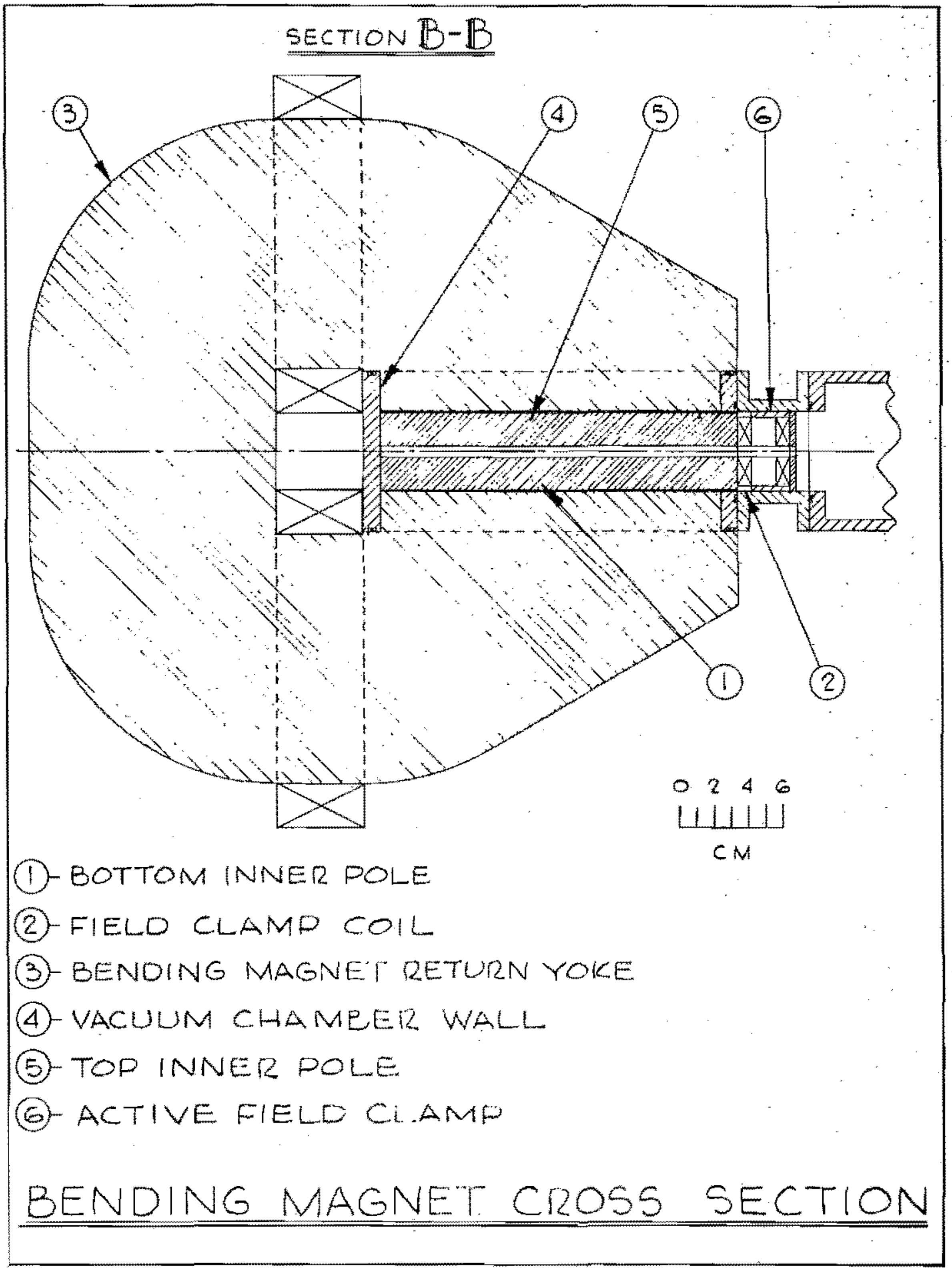
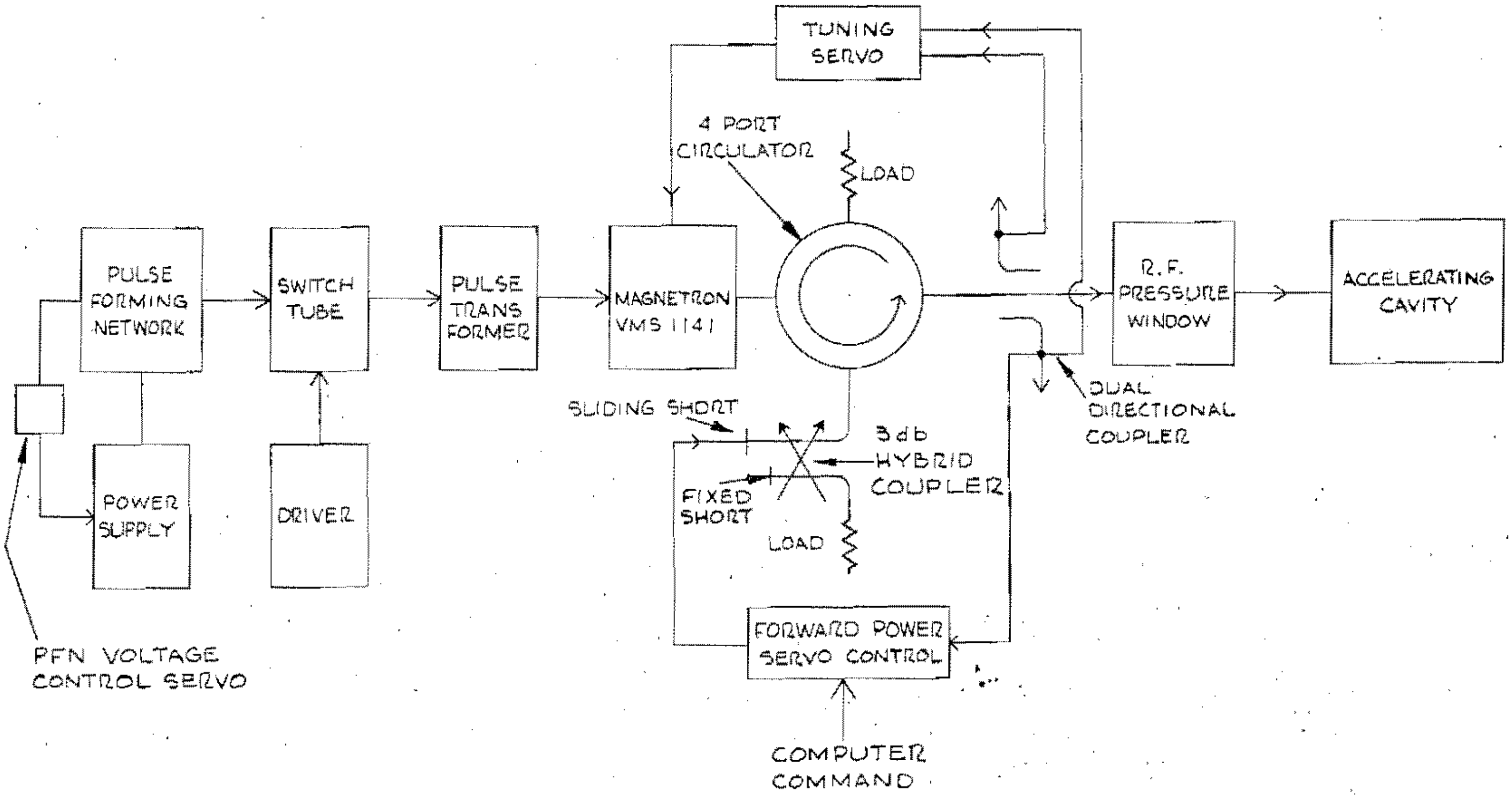
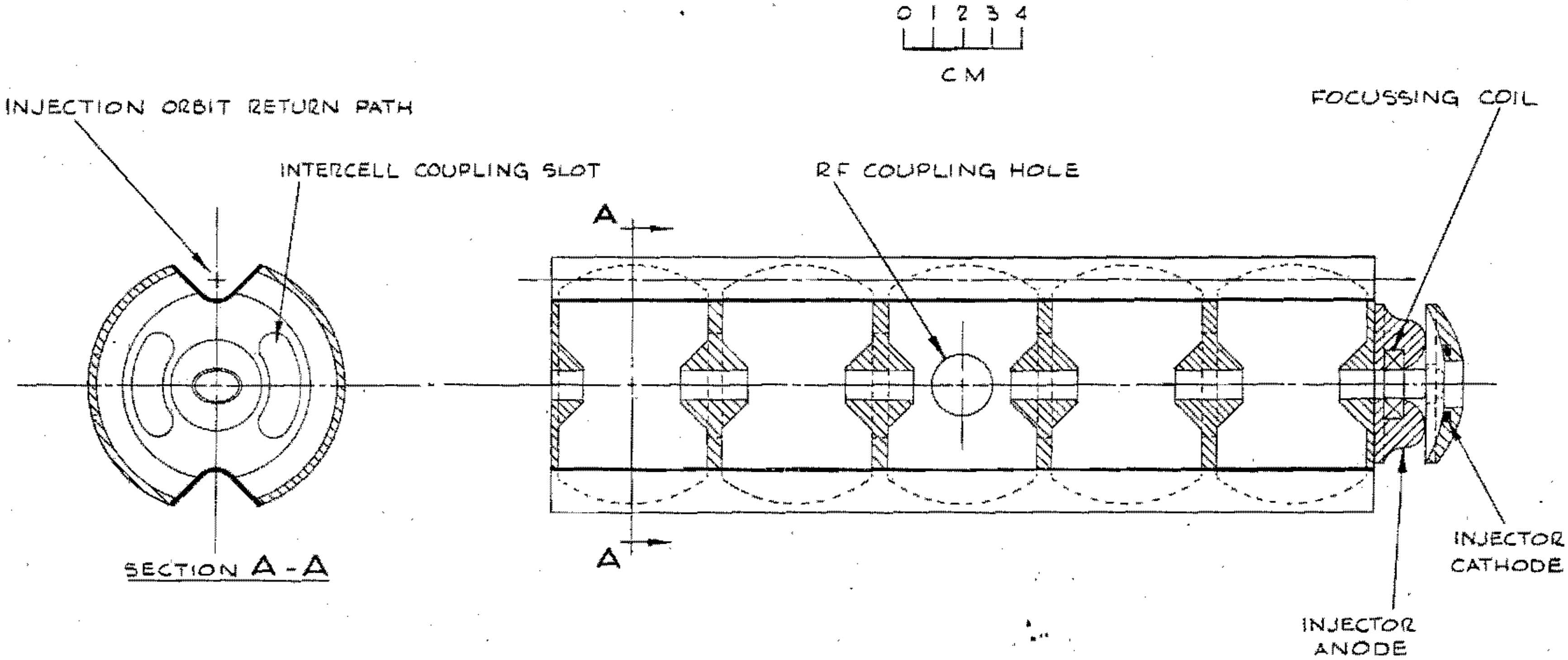

SECTION B-B
3
4
5
6
1
2
0 2 4 6
CM
1 - BOTTOM INNER POLE
2 - FIELD CLAMP COIL
3 - BENDING MAGNET RETURN YOKE
4 - VACUUM CHAMBER WALL
5 - TOP INNER POLE
6 - ACTIVE FIELD CLAMP
BENDING MAGNET CROSS SECTION

Figure 8



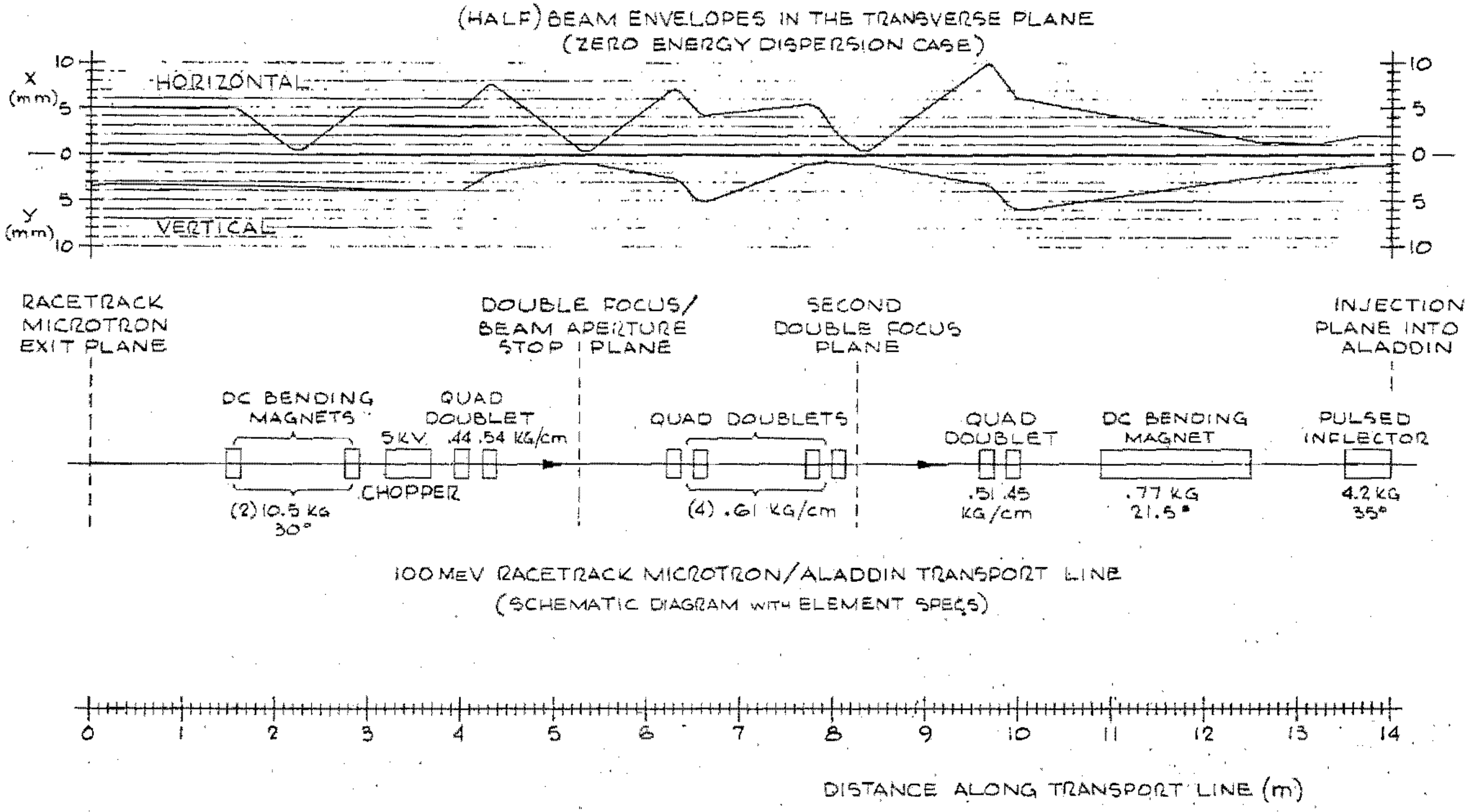
MICROTRON R.F. SYSTEM

Figure 9



5 CELL π MODE ACCELERATING STRUCTURE & INJECTOR

Figure 10



(HALF) BEAM ENVELOPES IN THE TRANSVERSE PLANE
(ZERO ENERGY DISPERSION CASE)
X (mm)
Y (mm)
HORIZONTAL
VERTICAL
RACETRACK MICROTRON EXIT PLANE
DOUBLE FOCUS/ BEAM APERTURE STOP PLANE
SECOND DOUBLE FOCUS PLANE
INJECTION PLANE INTO ALADDIN
DC BENDING MAGNETS
(2) 10.5 KG 30°
5KV CHOPPER
QUAD DOUBLET .44 .54 KG/cm
QUAD DOUBLETS
(4) .61 KG/cm
QUAD DOUBLET
.51 .45 KG/cm
DC BENDING MAGNET
.77 KG 21.5°
PULSED INFLECTOR
4.2 KG 35°
100 MeV RACETRACK MICROTRON/ALADDIN TRANSPORT LINE
(SCHEMATIC DIAGRAM WITH ELEMENT SPECS)
DISTANCE ALONG TRANSPORT LINE (m)

Figure 11

will also permit the control of the number and circumferential distribution of bunches filled. The second pair of quadrupole doublets produce a de-magnified image of the source which is in turn transformed in betatron phase space by the remaining beam transport system elements so as to match the admittance ellipse of Aladdin at the injection plane.

Injection of the electrons into Aladdin will follow conventional multi-turn techniques. The scheme is illustrated schematically in Fig. 12 which gives a phase space representation of the Aladdin injection plane on which are shown the Aladdin admittance area, the microtron emittance area, and the boundaries imposed by the injection septum and the vacuum chamber. At injection time the Aladdin admittance area is deflected by the upstream kicker so that a portion of it overlaps the area behind the septum. This deflection is corrected for by the downstream kicker, thus, electrons injected into the overlap area follow the normal orbit around the machine until they reach the upstream kicker whence they again follow the deflected orbit. During the time required for one orbit (0.23 μ sec) the excitation of the two kickers is reduced sufficiently so that the electrons will now pass on the right side of the septum and will remain in the machine. Now, more electrons will be injected into the remaining overlap area, and, in fact, the process will continue for the time required for five orbits before the overlap area becomes zero with all the electrons injected executing stable betatron oscillations within the admittance area which will now be centered about the position of the central (undeflected) orbit. With the 30 mA pulsed beam current expected from the microtron and taking account for the approximately 66% loss due to the chopper, the current accumulated in each injection event will be about 50 maA. In the storage ring the electron transverse momenta damp so as to occupy a very small region at the center of the admittance ellipse within a few seconds of injection and then the process may be carried out again. This injection scheme, which is called stacking, is now used with considerable success to inject into Tantalus I. Prototypes of the Aladdin injection elements (inflector and kickers) have been in operation for the past four years on Tantalus I.

Computer monitoring and control of accelerators is now a highly developed technology and the high level of performance and reliability required of Aladdin makes it imperative that this technology be exploited. Fortunately, the continued rapid development of microprocessors and standard I/O modules, such as CAMAC, has made it possible to set up a special purpose computer network, such as will be required to monitor and control the many subsystems of Aladdin, at considerably less cost than previously. The philosophy we have chosen to follow in instituting computer control of Aladdin is as follows. The main control computer of the system would be a fairly large minicomputer such as the Interdata 7/32 which, if more capacity is required, can be upgraded to the Model 8/32 with "plug in" modifications, but without any change in codes. This computer would act as an executive presiding over an array of micro-processors, one or more at each subsystem of the ring. The microprocessors

RADIAL PHASE SPACE DIAGRAM OF INJECTION INTO ALADDIN
- INFLECTOR EXIT VIEW

(zero energy dispersion case; shown is first turn
injection at full kicker excitation)

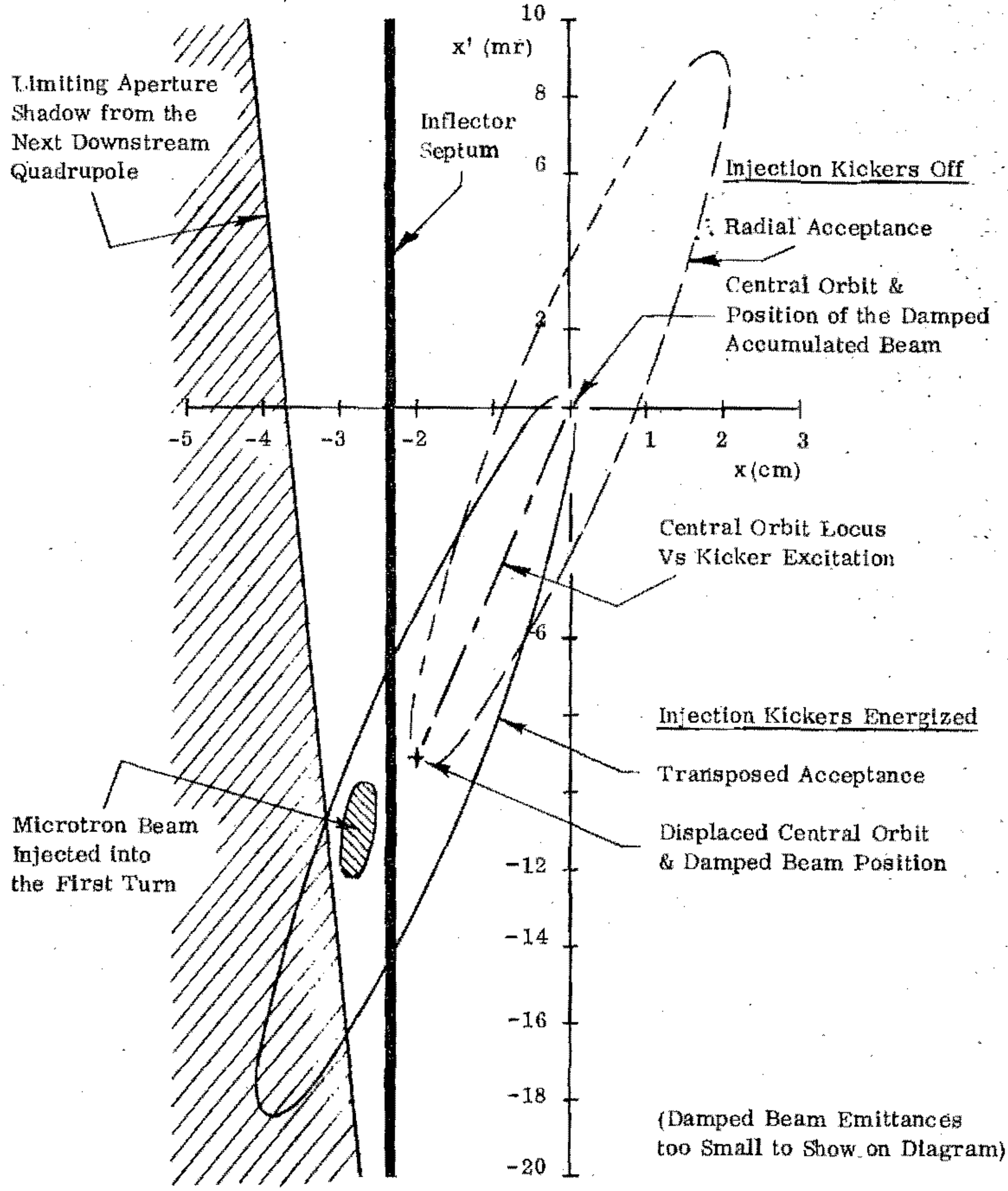


Figure 12

would communicate to the subsystems through standard I/O systems such as CAMAC. In operation, the microprocessors would be responsible for the direct control of the subsystems according to programs fed to them by the executive computer. One of the most important functions of the microprocessors, particularly during the running-in period, will be that of monitoring the performance of the subsystems with as high an update rate as possible. To have an "instant playback" of systems parameters to diagnose intermittent abnormal operation or systems failure should be invaluable in debugging the storage ring.

As the radiation facility develops, other tasks that the computer network will be expected to take on are monitoring the status of the photon beam lines and the responsibility for fast dump of the stored beam in the event of subsystems failure.

During stored beam time and machine downtime when the demands on the executive computer are minimal, it will be made available to the users for program development, simple data reduction tasks and mass data storage and transfer.

By installing one additional quadrupole in each unit cell as shown in Fig. 13, Aladdin will become Super Aladdin. No other changes in the basic machine structure are necessary. The result of this modification will be an increase in source brightness in the bending magnets by a factor of seven. For many experiments this will be equivalent to increasing the circulating beam current by a factor of seven but without the increased radiation hazard such an increase in beam current would occasion. The reasons for this remarkable result may be seen from the plots of the β and η functions shown in Fig. 14. From these it can be seen that adding the extra quadrupoles has the effect of converting each unit cell into a low β insertion with the minimum beam cross section occurring at the photon source points in the bending magnets. From Fig. 15, however, it can be seen that the behavior of the beam in the long straight sections is essentially unaffected, thus the possibility of installing helical wigglers will not be compromised by upgrading Aladdin to Super Aladdin.

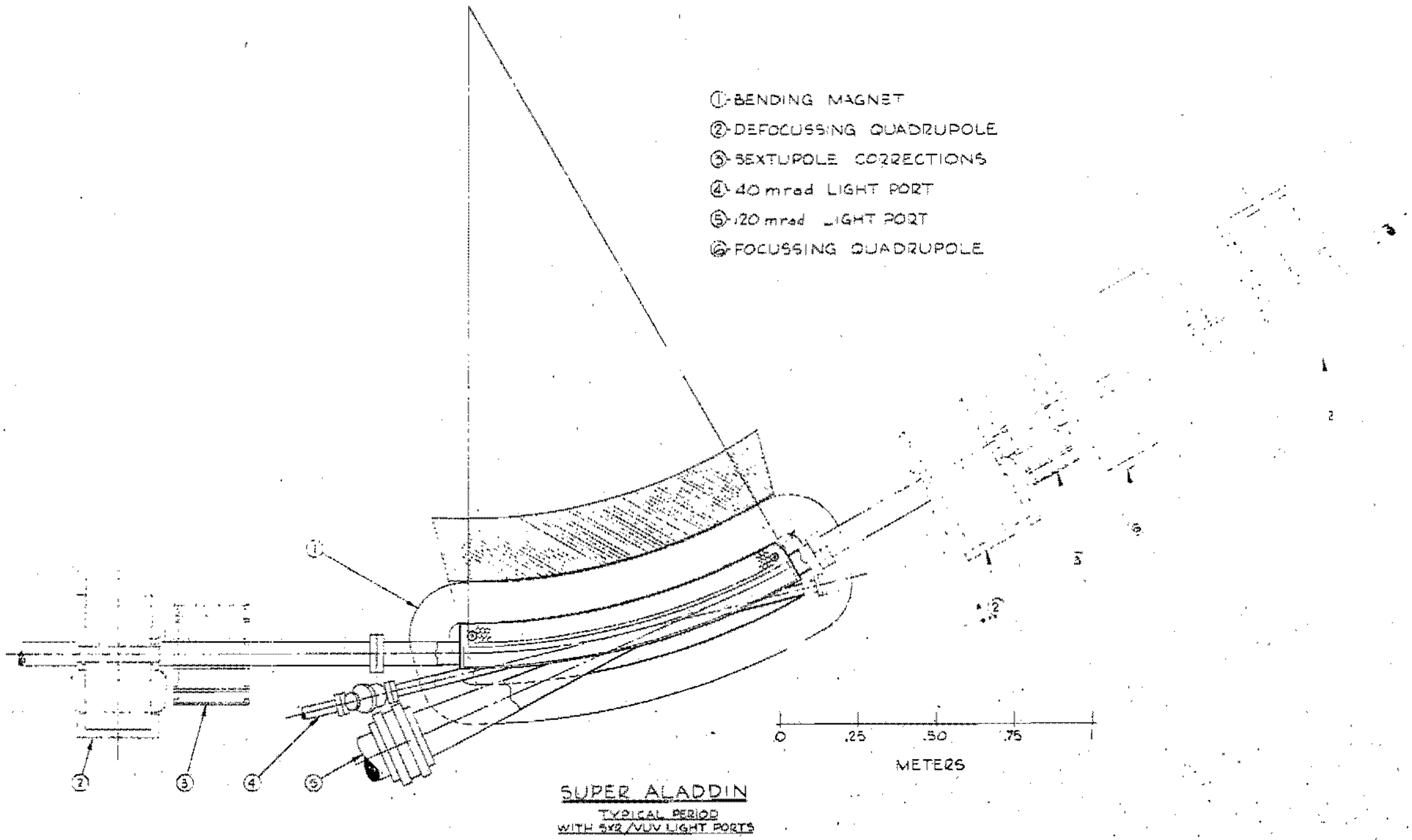

①-BENDING MAGNET
②-DEFOCUSSING QUADRUPOLE
③-SEXTUPOLE CORRECTIONS
④-40 mrad LIGHT PORT
⑤-120 mrad LIGHT PORT
⑥-FOCUSSING QUADRUPOLE
0 .25 .50 .75 1
METERS
SUPER ALADDIN
TYPICAL PERIOD
WITH SXR/VUV LIGHT PORTS

Figure 13

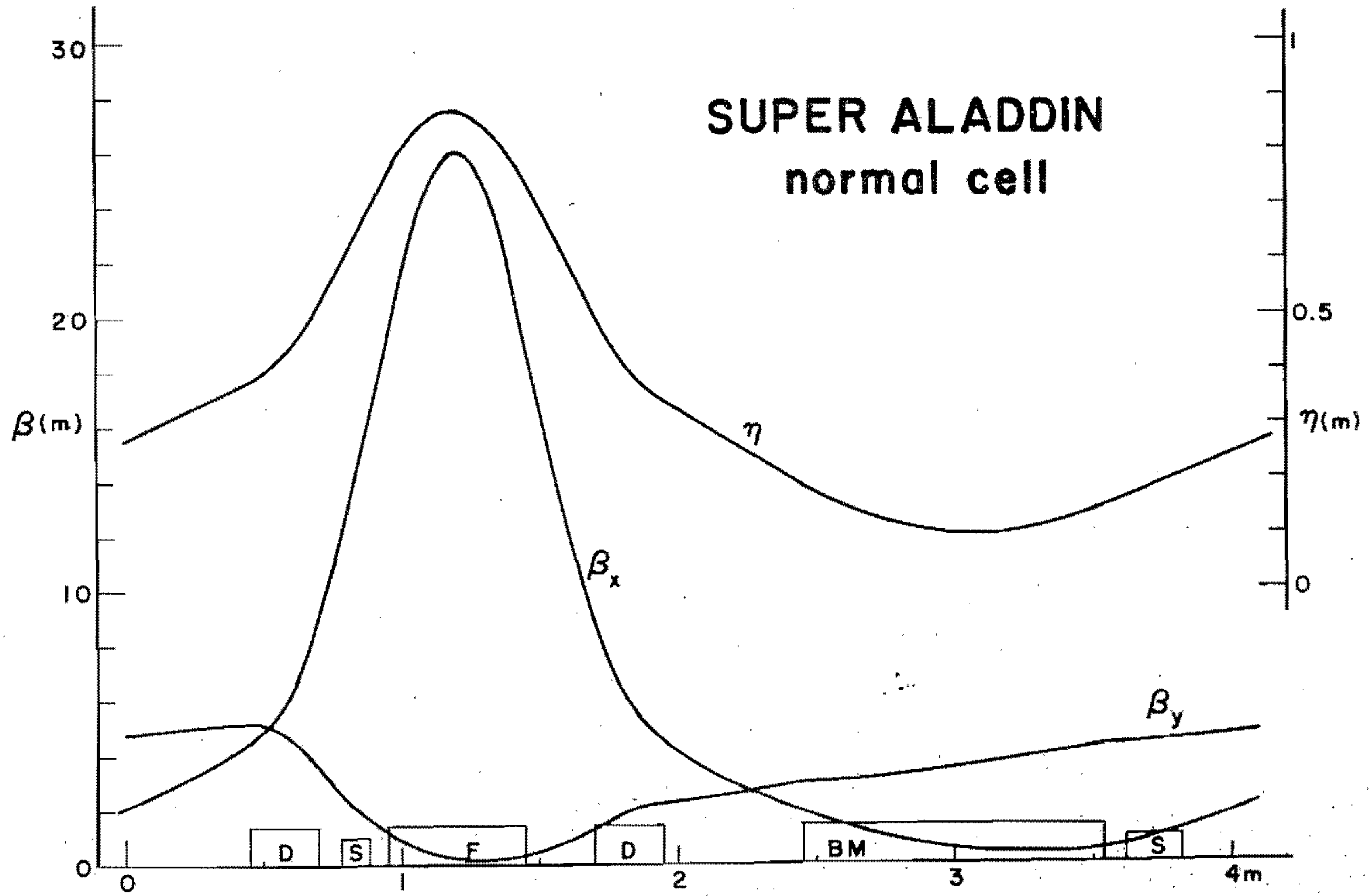

SUPER ALADDIN
normal cell
β(m)
30
20
10
0
η(m)
1
0.5
0
η
βx
βy
D
S
F
D
BM
S
0
1
2
3
4m

Figure 14

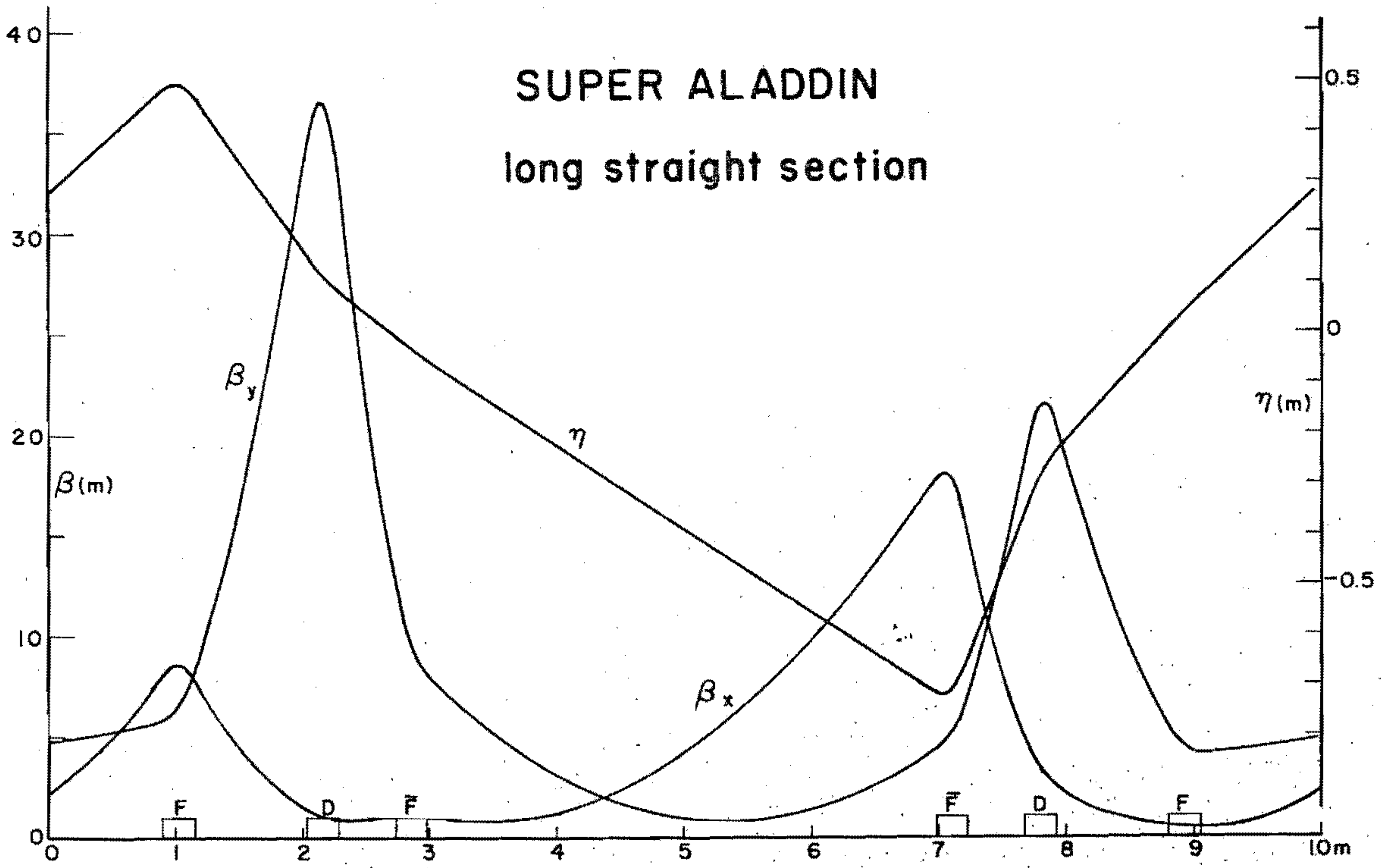

SUPER ALADDIN
long straight section
40
30
20
10
0
β(m)
β_y
η
β_x
η (m)
0.5
0
−0.5
F
D
F̄
F̄
D
F
0
1
2
3
4
5
6
7
8
9
10m

Figure 15

C. Special Options

Included in the basic design of the storage ring is sufficient space for special devices, should they prove to be desirable. Of the two long straight sections in Aladdin, one will be completely utilized by ring operation. The other has 4 meters of unobstructed space and a transverse wiggler could be installed in it. A transverse wiggler is a series of three dipole magnets arranged to give no net deflection to the electron orbit, yet one of the magnets can have a very high field, say 50 kG. At 750 MeV. This high field magnet would yield a hard x-ray spectrum with $\lambda_c = 6.6$ Å (1.87 keV). The brightness of this wiggler source can be improved: With proper rearrangement of the quadrupoles in a long straight section, it is possible to reduce the source size at the dipole wiggler and make the source at least 5 times brighter than the bending magnet sources of Aladdin. This application of the so-called "low β insert" was first proposed by the SRC staff[17].

Another device that could be inserted in Aladdin is the helical wiggler, a double-wound helical coil that produces a magnetic field that (1) is perpendicular to the coil axis and (2) rotates in space with the pitch of the coil. While no net deflection of the electron orbit occurs, the relativistic electrons see the helical wiggler as a circularly polarized plane wave and radiate in a narrow band of wavelengths centered at $\lambda_H = \lambda_o (1 + K)^2 / \gamma^2$ where λ_o is the helix pitch, K is proportional to the helix magnetic field, and γ is the electron energy in units of electron rest mass. The wiggler source is tunable by varying either the electron energy or the coil field, can yield 100 times more intensity than a regular storage ring source, and does so in a relatively narrow bandwidth around λ_H.

A helical wiggler with a small pitch λ_o and therefore small bore could not be directly installed on Aladdin because of the relatively large cross section of the beam from the 100 MeV microtron at injection. However, Tantalus I will be available as a damping 240 MeV booster ring for Aladdin should the decision to install such a helical wiggler in this machine be made. The small damped beam of Tantalus I could be easily injected into Aladdin, even with a helical wiggler in the long straight section. For a helical wiggler with $\lambda_o = 1$ cm on Aladdin, $\lambda_H \approx 23.2$ A (534 eV).

The effects of both of these special insertions on the operation of the storage ring have been studied in some detail by the design group. These studies indicate that, while both types of wigglers can be accommodated by the storage ring with little or no degradation of its function as a storage ring, the installation of these devices will have effects on the storage ring as a synchrotron radiation source. These effects were considered at considerable length during the 1976 Quebec Summer Workshop on Synchrotron Radiation Facilities and the results of these considerations are reported in the proceedings of this meeting[19]. The summary of these results is that the helical wiggler will cause a reduction of brightness at the normal bending magnet source points because of the unavoidable enlargement of the electron beam vertical dimension and that energizing a transverse wiggler will result in some transverse motion of the normal source points. To an extent this latter effect can be controlled through the use of steering corrections, however it cannot be made to vanish for all possible ring and wiggler operating conditions. Thus the decision to implement such devices on a synchrotron radiation source serving a large and varied research program is not to be made lightly.

It is important to note that each of the long straight sections, whether in Aladdin or Super Aladdin, has ample space for the necessary orbit correcting elements. With proper design, any wiggler can be made to have minimal impact on the regular experimental program.

D. Beam Lines and Instrumentation

With the exception of experiments mounted on a possible high field wiggler magnet beam, all of the experiments done on Aladdin will be done in the vuv and soft x-ray regions (where soft x-rays are defined as $h\nu$ <3 keV) primarily with instruments using diffraction gratings for dispersion, although improved crystals for the 4 to 20 Å region may make crystal dispersion more desirable in the future for high resolution experiments.

Aladdin has 12 bending magnets and two long straight sections. Two ports can be attached to the vacuum chamber in each of the bending magnet regions to provide one beam of 42 horizontal milliradians and another beam of 120 horizontal milliradians. One of the long straight sections is occupied by injection and extraction hardware, but the other one is intended for the installation of wigglers. The 24 bending magnet ports can provide a total of 1.9 radians of beam, so about 30% of the synchrotron radiation generated will be available for use.

One of the very important Aladdin design features is the small radius of curvature which permits placement of mirror optics close to the source point but outside of the storage ring vacuum chamber. Even though material damage is not expected to be a problem with optics on Aladdin, carbon deposits on mirror surfaces are expected even in uhv beam lines, and periodic cleaning and recoating of optical elements will be necessary. To have to open up the ring chamber to do this imposes many difficulties with scheduling and with the integrity of the ring vacuum. Therefore, mirrors will be on kinematic mounts in mirror box - vacuum pumping stations which can be valved off from the rest of the beam line and the storage ring. Removal, cleaning, recoating (if necessary), and replacement of mirrors will be simple operations compared with similar procedures with cooled metal mirrors. Another advantage of the short radius of curvature of Aladdin is that beam lines similar to those used at Tantalus I can be installed on Aladdin with any necessary shielding between the storage ring and the mirror chambers. This means the mirrors are accessible for manual adjustment or maintenance with beam stored in the ring; also, components and even entire beam lines including monochromators and sample chambers can be set up on Tantalus I for testing so that lead time for Aladdin as an operating facility can be reduced. Tantalus I will be useful as a test facility down to about 40 Å (~ 300 eV) so most grating instruments could be tested quite well. This capability of testing on Tantalus I also implies that instruments now in use on Tantalus I could be installed on Aladdin and also that instruments built for use on Aladdin could be used on Tantalus I until Aladdin is commissioned. Exploitation of both of these possibilities will accelerate the early operating phase of Aladdin at which about 14 monochromatic experiment stations will be operative.

The general concept of Aladdin beams will be similar to the ones used on Tantalus I from which a great deal of experience has been gained.

The 42 mrad lines will have a scatter-free, recessed portion of vacuum chamber and a viewport directly behind the source point. This will not only permit laser alignment schemes to be used but will also prevent high energy electrons, γ-rays and neutrons from being scattered directly down the beam line. Connections to the beam line ports will be with copper gasketed seals of the highest integrity. The first valves will be metal sealed gate or straight-through valves and they will be followed by fast acting valves for protection of the ring vacuum against accidents. Beam occulting shutters will be used to prevent illumination of optical surfaces except during actual use. This will reduce surface contamination as well as eliminate the need to close the metal sealed valves frequently and thereby prolong the seal life.

Mirrors similar in design to those now used at the Synchrotron Radiation Center will be quite suitable for use with Aladdin. We have considerable experience with the design, fabrication and utilization of grazing incidence, first-surface mirrors for vuv and soft x-ray applications.

Grating monochromators in both the normal incidence (NI) region (300 Å to 3,000 Å) and the grazing incidence (GI) region (< 400 Å) have been used extensively at the Synchrotron Radiation Center. The design and construction of several of these at the Synchrotron Radiation Center-Physical Sciences Laboratory has led to a high level of expertise in this field. The vertical Seya-Namioka, and the "Grasshopper" grazing incidence monochromators designed and built at the Synchrotron Radiation Center-Physical Sciences Laboratory, and the large 4-meter normal incidence monochromator, planned for installation at the Synchrotron Radiation Center, will form the basis of general purpose monochromators unless new grating developments such as the J.Y. toroidal holographic grating indicate that other instruments could be matched more efficiently to the source. It is expected that high resolution grating monochromators for the 4 Å to 100 Å region will have to be specialized short scanning range instruments.

For the initial phase of operation of Aladdin, we plan to provide monochromatized beams to 14 experimental stations utilizing instruments now installed at Tantalus I and instruments that will be acquired under the present SRC operations grants during the Aladdin construction period. A listing of these instruments is given in Table VI. A discussion of future instrumentation is given in Appendix IV.

Table VI. Monochromators to be available at the SRC by 1/1/79

Quantity	Type	Remarks	Ownership	Status
1	1 Meter Vert S-N(1)	High Vacuum	SRC	Operational
1	1 Meter Vert S-N	Int. Vacuum	SRC	Operational
1	1 Meter Vert S-N	Int. Vacuum	Taylor UW-M	Operational
1	1 Meter Vert S-N	High Vacuum	SRC	Planned
1	1.5 Meter S-N(5)	High Vacuum-Low Resolution	SRC	In Construction
1	0.5 Meter S-N	McPherson 235	Fritzsche UC	Operational
1	1 Meter NI(2)	High Vacuum	SRC	Operational
1	1 Meter NI	McPherson 225	Lynch ISU	Operational
1	1 Meter NI	McPherson 225	Hurych NIU	Operational
1	4 Meter Vert NI	High Resolution	SRC	In Construction
1	2 Meter Vert G^2IM(3)	High Vacuum	SRC	In Construction
1	2 Meter Vert G^2IM	High Vacuum	SRC	Planned
1	2 Meter Vert GIM(4)	Hilger Watts	Brown UI	Operational
1	2 Meter Vert GIM	Int. Resolution	Judge USC	Operational
1	2 Meter GIM - 1 Meter S-N	Hybrid Mono.	Eastman IBM	Operational

(1) S-N: Seya-Namioka
(2) NI: Normal Incidence
(3) G^2IM: "Grasshopper" Grazing Incidence
(4) GIM: Grazing Incidence
(5) Horizontal dispersion instrument. Vertical dispersion instruments are denoted by inclusion of the term Vert in the type description.

E. The Expanded SRC Building

A building suitable for a synchrotron radiation facility is essentially an extremely large optical table, suitably air-conditioned and temperature-controlled, and with provision for the necessary radiation shielding.

In order to achieve high brightness, a storage ring for the production of synchrotron radiation is designed for minimum beam cross section. If this design goal is to be achieved, magnet alignment errors (which cause coupling of the radial and vertical particle motions) must be minimized. If the facility is to operate for an extended period of time with no change in source characteristics, the mechanical alignment of the storage ring must be maintained within narrow tolerances. The required stability extends to the beam lines and experimental areas. A source approximately 150 microns high must be imaged to an entrance aperture of this dimension or less at a distance of many meters. If beam motion at the experiment is not to be a limiting source of error, the relative positions must be maintained within a few microns.

The site at Wisconsin is geologically very favorable. Nearly flat bedrock lies 6 to 10 feet below the surface and will serve as an extremely stable base for the machines and the experimental areas. Indeed, the location of the laboratory was originally chosen because of its suitability as an accelerator site.

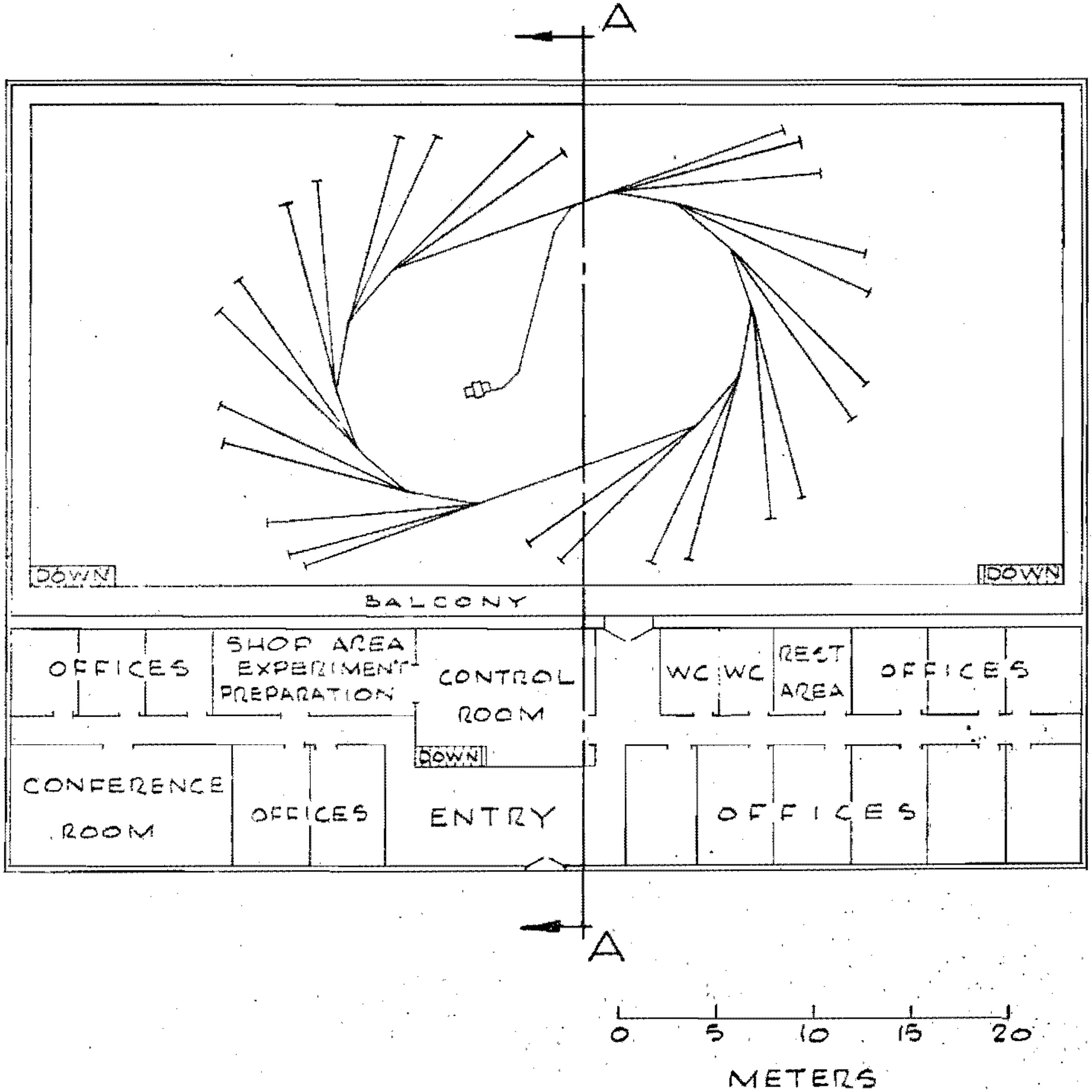
Once the floor stability requirements are met, other requirements are met by normal laboratory construction. With careful mechanical design of the storage ring, beam lines and monochromators, experience with Tantalus I has shown that the necessary thermal stability is within the range of conventional heating and air-conditioning control systems. The building air-conditioning system will maintain low humidity because of the adverse effect of water vapor on ultrahigh vacuum systems, storage ring and instrumentation.

The radiation shielding requirements are vastly different during injection and stored beam operation. In order to provide optimum access to the synchrotron radiation, shielding immediately around the storage ring will be adequate only for the stored beam condition. In order to cope with the higher levels of radiation during injection, the storage ring and experimental areas will be evacuated during injection. The location of the storage rings below ground will provide the necessary exterior shielding at low cost.

It is impossible to completely predict the future location of experiments with respect to the storage ring. In order to minimize potential future conflicts in positioning beam lines, floor obstructions such as cable trays and junction boxes will be kept to a minimum and carefully located. Utilities (ac power, low volume cooling water, dry N_2 gas and compressed air) for the experimental area will be brought out along beam lines from distribution manifolds at the base of the storage ring.

The building for the intermediate energy storage ring Aladdin, which is shown in Fig. 16, will be constructed with funds to be made available by the Graduate School of the University of Wisconsin-Madison. It will be a single-story steel framed, insulated, metal building (160 feet by 136 feet) with below grade walls of poured concrete. The storage ring and experimental area will be 160 feet by 95 feet with a 20 feet ceiling height. The building will permit beam lines of at least 30 feet from all magnets, with the option of extending some beam lines, including those from the straight sections, to as much as 70 feet. The microtron, with local shielding, will be located in the center of the ring to avoid interference with the beam lines. Space around the perimeter of the building will be used for individual experiment work areas. The remaining 160 feet by 41 feet area on the basement level will be separated by a concrete shielding wall, and will be available for loading, experimental set up, power room, and experiment storage. An above grade level over this area, also behind the shielding wall, will house the control room, conference room and offices for the operations group and the investigators.

Light duty cranes will be used in the experimental area of the building to handle experimental equipment. The installation and removal (if necessary) of magnets will be done with special purpose rigging.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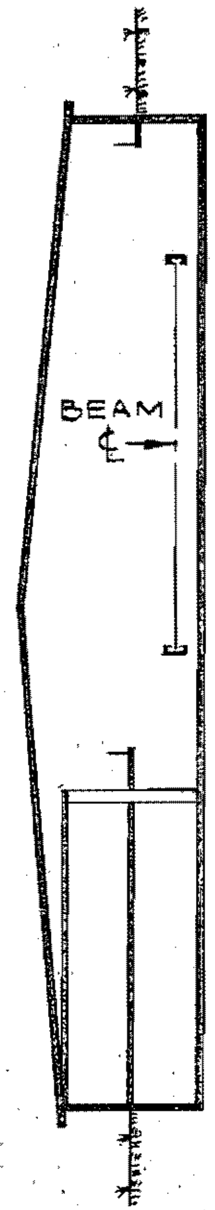
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SECTION A-A

F. Radiation Safety

In discussing questions of radiation safety around electron storage rings operated as synchrotron radiation sources, one must keep in mind a fundamental operational difference between electron storage rings and electron synchrotrons. In an electron synchrotron particles are injected, accelerated, and brought on target up to 60 times per second. Therefore, the radiation generated by synchrotrons tends to be high, in fact as high as possible. Conversely, in a properly constructed electron storage ring, charged particles in the amount corresponding to that in a single accelerated pulse in a synchrotron are stored for many hours, thus the generated radiation levels around electron storage rings are typically 4 to 5 orders of magnitude lower than are commonly encountered about electron synchrotrons of the same energy. From the very beginning, then, the problem presented to the radiation safety engineer by a storage ring is materially reduced. In fact, the only time that radiation safety is a problem around a properly operating electron storage ring is during injection when, unavoidably, a considerable amount of stray radiation is produced by lost particles.

In normal operation under stored beam conditions, the only radiation emanating from an electron storage ring results from the slow loss of particles from the stored beam due to collisions with residual gas molecules and to Touschek effect. The lost electrons resulting from these processes may be rendered essentially harmless by the use of in-vacuum tank beam scrapers that direct the resulting radiation into a safe beam dump. Under abnormal conditions, that is to say when through some malfunction the electron beam is lost abruptly, reliable, well-proven techniques may be used to remove the entire stored beam within a very few revolutions and deposit it in a safe beam dump. Thus the shielding requirements around an operating electron storage ring may be termed minimal. Indeed, experience gained with the operation of Tantalus I, the machine at the Wisconsin radiation center, over the last eight years has shown that no user has received a measurable dose even though the investigators work in close proximity to the machine with no intervening shielding. It is expected that Aladdin, a machine of approximately the same class as Tantalus I, would be similarly safe to work around.

To minimize danger from radiation generated during the injection process, the machine will be mounted below grade level. Mounted this way, Aladdin, because its injection energy is relatively low, can be covered by a conventionally constructed roof. Tests conducted at the Synchrotron Radiation Center on Tantalus I during injection have shown that the sky shine generated is within acceptable limits. Since the injection energies of both Aladdin and Tantalus I are comparable, it is expected that Aladdin will represent a similarly small radiation hazard during injection. During injection, of course, all personnel will vacate the vicinity of the machines.

Finally, one other aspect of radiation safety needs comment here. This is the possibility of electrons circulating in the machine targeting on portions of the vacuum chamber so that high energy secondary radiation may come directly down the photon beam lines. This possibility, while remote, may be dealt with through proper construction of the vacuum chamber. Obstructions will be placed in the vacuum chambers so that electrons on such distorted orbits will produce their secondaries in directions which will not go down the photon beam lines.

G. The University of Wisconsin-Madison as a Site

The suitability of the University of Wisconsin as the site of a greatly expanded national facility for synchrotron radiation research can be easily established. Firstly, the University is itself the site of both an extremely large and active group of investigators working in the chemical and biological sciences and a growing, active group working in materials research. These groups are a potential large source of investigators to make use of the vacuum ultraviolet capabilities of the expanded facility. The Chicago area, which is within easy driving distance of the University of Wisconsin, boasts of the University of Chicago and the Argonne National Laboratory, both large sources of potential users for the vacuum ultraviolet and soft x-ray ranges. In both institutions work is being carried out in chemistry, biology and the material sciences for which access to such a facility could be crucial. The Ames Laboratory, while not as close to the University of Wisconsin as the institutions in the Chicago area, is nevertheless another source of users with similar interests, in particular in the materials research area. Closer than the Ames Laboratory is the Materials Research Laboratory at the University of Illinois, generally considered to be the finest materials research laboratory in the United States. Serious interest has already been expressed on the part of the Illinois Materials Research Laboratory in access to a synchrotron radiation source of the capabilities being proposed by the University of Wisconsin. Finally, it should be pointed out that it has been quite conclusively demonstrated that investigators working in the vacuum ultraviolet from the entire United States have been perfectly willing over the past several years to come to Wisconsin to pursue their researches.

Another and more important reason for the suitability of the University of Wisconsin as a site for a national synchrotron radiation facility is the existence of an established, operating, productive national synchrotron radiation research center there. Associated with, and responsible for, the operation of this center is a group of accelerator builders including physicists, engineers, and technicians of demonstrated capability in the design and construction of electron accelerators. Further, this group has been responsible for the development and operation of the existing facility, a facility which has achieved world-wide recognition for both the excellence of the research carried out there and the smoothness of its operation.

Finally, the University of Wisconsin has demonstrated over the past eight years its willingness to support the existing facility in deeds rather than words. That the University of Wisconsin will support this proposed program to greatly increase the capabilities of the Synchrotron Radiation Center in the same manner is demonstrated by its commitment to make land for this expansion available, to construct the building necessary for the intermediate energy machine Aladdin, and its willingness to make the considerable capabilities of the Physical Sciences Laboratory available for the construction of these machines and the support of the operation of the expanded facility when it becomes operational.

The Physical Sciences Laboratory, which now employs some 40 scientists, engineers, technicians, and administrative personnel, has amply demonstrated its capabilities to support the present synchrotron radiation facility at the University of Wisconsin. In addition, it has supported the programs of the high energy physics group of the University of Wisconsin working at the Fermi Lab and the SPEAR colliding beam facility in the construction of very large and sophisticated experimental gear. Thus the design, construction, and operation of the proposed machines are well within the capabilities of the Physical Sciences Laboratory and the staff of the Synchrotron Radiation Center.

Madison, the home of the University of Wisconsin, is easily accessible by air from Minneapolis, Chicago, Denver, and Milwaukee. It is also accessible on a direct flight basis from New York City and Washington, D. C.

Funds for the construction of a guest facility on land adjacent to the Physical Sciences Laboratory have been requested. This building, which was designed with extensive user input, would form the first unit of the low cost, on site housing specified in Section I.

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CURRICULUM VITAE

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Midwestern Universities Research Association, Physicist 1956-1960.
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University of Wisconsin, Physical Sciences Laboratory, Senior Scientist 7/69 through 12/74.
University of Wisconsin, Physical Sciences Laboratory, Chief Scientist 1/75 to present.
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Ultrahigh vacuum techniques
Optical systems for soft x-ray beams

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National Accelerator Laboratory
Los Alamos Scientific Laboratory
National Academy of Sciences

MEMBERSHIP IN PROFESSIONAL SOCIETIES

American Physical Society
ΣΠΣ
ΣΞ

PUBLICATIONS:

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E.M. Rowe, M.A. Green, W.S. Trzeciak, and W.R. Winter, Jr., "An Advanced Electron Storage Ring System for Synchrotron Radiation Research," Fifth All-Union National Conference on Particle Accelerators, Dubna, USSR, October 5-7, 1976.

IV. Budget Summaries

A. Construction Budget

The costs for special facilities, which are the storage ring and its ancillary systems, are based upon the engineering and scientific needs of the construction project being provided by the Operations Group of the Synchrotron Radiation Center of the University of Wisconsin-Madison and the Physical Sciences Laboratory of the University of Wisconsin-Madison, and reflect these groups' experiences in the design, construction, and operation of the present facility as well as their extensive experiences in the design and construction of major projects in high energy physics and other fields.

The building to house the storage ring system and to provide space for the research program will be a University of Wisconsin-Madison contribution to the project. However, funds for heating, ventilating, and air conditioning as well as for plumbing and electrical services are included in this submission. These costs are based upon estimates prepared by the Wisconsin Department of Planning and Construction and reflect their experience with similar construction projects in the Madison area.

Engineering, design, and inspection costs include the salaries of the professional personnel required to design, develop, and put into operation the storage ring system. Included in this item are indirect costs and fringe benefits. Indirect costs are charged at the rate of 59% of salaries, a rate that was fixed in the negotiated agreement dated April 19, 1976 between the University of Wisconsin and the Department of Health, Education and Welfare, the cognizant negotiating agency of the federal government. The University contribution for fringe benefits is charged directly to the appropriation from which the employee's salary is paid. Fringe benefit rates effective July 1, 1976 for regular academic salaries are 20.4%.

Covered under standard equipment are the office furniture, file cabinets, storage cabinets, work benches, laboratory benches, and other such items necessary to equip the office and experimental areas of the facility.

CONSTRUCTION BUDGET

FY 1978-79-80

Site Development and Building; University of Wisconsin Contribution ($600,000)		$ -0-
General Construction		
	HVAC	$ 180,000
	Plumbing	28,000
	Electrical	62,000
Total Building Costs		$ 270,000
Special Facilities		
	A. Microtron	$ 182,000
	B. Guide Fields	653,000
	C. Vacuum Systems	167,000
	D. R.F. Systems	272,000
	E. Injection Systems	20,000
	F. Extraction System	24,000
	G. Beam Transport System	100,000
	H. Control System	294,000
	I. Computer	212,000
Total Special Facilities		$1,924,000
Engineering, Design, and Inspection 25% of Special Facilities		$ 481,000
Crane Facilities		$ 90,000
Shielding, movable		$ 15,000
Standard Equipment		$ 150,000
Total Construction Costs		$2,930,000

B. Facility Operating Costs

Estimated annual costs of operating the expanded facility for FY 1980-81 are given below. The senior personnel and facility support group personnel listed will be required to maintain a satisfactory level of facility performance, to improve the operation of the facility, and to make such modifications and improvements to the storage ring, to its injector, and to the facility experimental equipment as will from time to time become necessary to meet the ever increasing research requirements of the users.

Personnel listed as facility research personnel will have the dual responsibilities of aiding and collaborating with outside investigators as required and of carrying out a vigorous research effort in their own right. The existence of such a dual purpose in-house research group is necessary if the full potential of the expanded facility is to be realized.

Allocations for services, materials, and capital equipment are based on experience gained in the past eight years of operation of the present facility, taking into account the increase in the level of activity expected of the expanded facility.

Costs for salaries and services are estimated for 1980, taking into account expected increases in University hourly rates and salaries of professional personnel of a quality consistent with their responsibilities.

The travel funds listed will be used to allow facility personnel to attend and present reports at professional meetings, to assist members of the Users Executive Committee to travel to the Radiation Center for program committee meetings, and to bring a number of experts in various fields to the Radiation Center for consultation or to deliver colloquia during the operation year.

It is expected that, as in the past, the in-house group will be a prolific source of reports and papers of a quality suitable for publication in refereed journals. In addition, communications both by telephone and the mails from the Radiation Center to the investigators, including the production and distribution of the proceedings of the annual users group meeting, must be provided for. Costs incurred in these vital functions of a national research facility are not available from the University, by state law, thus funds are included in the projected annual costs.

ANNUAL OPERATING BUDGET

FY 1980-81

(12/1/80 - 11/30/81)

Direct Costs

Salary and Wages		
Senior Personnel:		
Director - Principal Investigator	12 person-months	$ 33,091
Senior Scientist	12 person-months	31,252
Chief Mechanical Engineer	12 person-months	32,595
Operations Manager	12 person-months	23,000
Facility Support Group:		
Physicist	24 person-months	42,500
Electrical Engineer	12 person-months	22,000
Programmer	12 person-months	22,000
Facility Research Group		
Scientist	48 person-months	76,000
Total Salaries		$282,438
Fringe Benefits - @ 20.4%		57,617
Total Salaries & Fringe Benefits		$340,055
Services		
Technicians	48 person-months	$129,456
Administrative Secretary	10 person-months	17,500
Total Services		$146,956
Capital Equipment		$ 50,000
Expendable Supplies		$ 75,000
Travel - Domestic		$ 10,000
Telephone, Communications, Publication		$ 7,500
Total Direct Costs		$629,511
Indirect Costs @ 59% of Salaries and Wages		$166,638
Total Annual Operating Costs		$796,149

CURRICULUM VITAE

December 1976

MICHAEL ANTHONY GREEN:

Project Associate, University of Wisconsin - Physical Scien es Laboratory.
Born June 4, 1945 in Vallejo, California. Married and has a daughter.
B. S. Applied Mathematics & Engineering Physics, University of Wisconsin-Madison, 1968.
M. S. Nuclear Engineering, University of Wisconsin-Madison, 1968.
Ph. D. Nuclear Engineering, University of Wisconsin-Madison, 1976.

POSITIONS:

Graduate Appointments - AEC & NASA Traineeships and Research Assistantship, 1967-1975.
Research Associate, National Accelerator Laboratory, Oak Brook, Illinois, Summer 1968.
Project Associate, U.W. Physical Sciences Laboratory, 1976-present.

RESEARCH & ENGINEERING INTERESTS:

General - design of particle confining, accelerating, and transport systems.
Specific - design, development, and application of high energy electron microtrons, of both conventional and racetrack types.

HONORS:

ΦΗΣ

PUBLICATIONS:

E. M. Rowe, M. A. Green, W. S. Trzeciak, and W. R. Winter, Jr., "The Conversion of the NBS 180 MeV Electron Synchrotron to a 240 MeV Electron Storage Ring for Synchrotron Radiation Research," 9th International Conference on High Energy Accelerators, SLAC, Stanford U., Stanford, Calif., May 1974.

M. A. Green, "The Design of the Microtron Injector for the UWPSL Storage Ring," Ph. D. thesis, U. of Wis.-Madison, 1976.

E. M. Rowe, M. A. Green, W. S. Trzeciak, and W. R. Winter, Jr., "An Advanced Electron Storage Ring System for Synchrotron Radiation Research," Fifth All-Union National Conference on Particle Accelerators, Dubna, USSR, October 5-7, 1976.

CURRICULUM VITAE

December 1976

ROGER A. OTTE:

Associate Scientist, Physical Sciences Laboratory, University of Wisconsin.
Born in Sheboygan, Wisconsin on May 12, 1932.
Married and has two children.
M.S. Physics, University of Wisconsin-Madison, 1960.

POSITIONS:

Midwestern Universities Research Association, Physicist, 1960-67.
University of Wisconsin, Physical Sciences Laboratory, Assistant Scientist, 1967-69.
University of Wisconsin, Physical Sciences Laboratory, Associate Scientist, 1969 to present.
Synchrotron Radiation Center of Physical Sciences Laboratory, University of Wisconsin, Operations Manager, 1972 to present.

RESEARCH INTEREST:

Particle Accelerator Physics

MEMBERSHIP IN PROFESSIONAL SOCIETIES:

American Physical Society

PUBLICATIONS:

D.E. Young, C.D. Curtis, R.A. Otte, F.L. Peterson, C.H. Pruett, F.E. Mills, C.A. Radmer, E.M. Rowe, M.F. Shea, D.A. Swenson, and W.A. Wallenmeyer, "Operation of the MURA 50 MeV Electron Accelerator," Bull. Am. Phys. Soc. II, 6, 447 (1961).

C.D. Curtis, A. Galonsky, R.H. Hilden, F.E. Mills, R.A. Otte, G. Parzen, C.H. Pruett, E.M. Rowe, M.F. Shea, D.A. Swenson, W.A. Wallenmeyer, and D.E. Young, "Beam Experiments with the MURA 50 MeV FFAG Accelerator," Proceedings of the 1963 International Conference on High Energy Accelerators at Dubna, U.S.S.R.

C.H. Pruett, R.S. Christian, G. Del Castillo, R.O. Haxby, J.R. Mulady, R.A. Otte, G. Parzen, W.A. Wallenmeyer, and D.E. Young, "Magnetic Guide Field Measurements and Corrections on MURA 50 MeV Electron Accelerator," Rev. Sci. Instr. 35, 1422 (1964).

C.H. Pruett, E.M. Rowe, R.A. Otte, and J.D. Steben, "Operation of an Electron Storage Ring as a Source of Synchrotron Radiation in the Vacuum Ultraviolet," Bull. Am. Phys. Soc., 14, No. 1, p. 17 (1969).

CURRICULUM VITAE

December 1976

PUBLICATIONS: (Cont'd.)

E.M. Rowe, R.A. Otte, C.H. Pruett, and J.D. Steben, "Operation and Performance of the U.W. Physical Sciences Laboratory Storage Ring," Paper B-36 presented at the U. S. Particle Accelerator Conference, Washington, D.C. - IEEE Transactions on Nuclear Science, 16, No. 3, pp 159-164 (1969).

E.M. Rowe, R.N. Dexter, J.D. Steben, and R.A. Otte, "The Operation of the University of Wisconsin Physical Sciences Laboratory Synchrotron Radiation Facility," proceedings of the Third International Conference on Vacuum Ultraviolet Radiation Physics, Tokyo, Sept. 1971.

CURRICULUM VITAE

December 1976

CHARLES H. PRUETT:

Senior Scientist, Physical Sciences Laboratory, University of Wisconsin.
Born in Corning, New York, April 21, 1928. Married and has two children.
Ph.D. Physics, Indiana University, 1958.

POSITIONS:

Midwestern Universities Research Association, Scientist-Physicist - 1956-1965.
Midwestern Universities Research Association, Head - 50 MeV Accelerator Group - 1965-1967.
University of Wisconsin, Physical Sciences Laboratory, Associate Scientist - 7/67 through 6/69
University of Wisconsin, Physical Sciences Laboratory, Senior Scientist - 1969 to present.

Security Clearances Held: AEC "Q" Clearance.

MEMBERSHIP IN PROFESSIONAL SOCIETIES:

American Physical Society, Sigma Xi, AAAS

AREAS OF RESEARCH, SPECIALIZED KNOWLEDGE, AND FIELDS OF INTEREST:

Particle Accelerator Design, Experimental Beam Dynamics in Particle Accelerators, Accelerator Magnetic Field Corrections, Instability Phenomena in High Intensity Charged Particle Beams, Experimental Studies of Radio Frequency Acceleration of Charged Particles, Electronics, Vacuum Ultraviolet and Soft X-ray Instrumentation and Research.

PUBLICATIONS:

See attached list.

PUBLICATIONS

Order of Gamma-Ray Emission in the Decay of In^{111}. M.M. Miller, C.H. Pruett, R.G. Wilkinson. Phys. Rev. 84, 849-50 (1951) November 15.

The Disintegration Scheme of V^{48}. Paul L. Roggenkamp, Charles H. Pruett, and Roger G. Wilkinson. Phys. Rev. 88, 1262-5 (1952) December 15.

Disintegration of Ce^{139}. Charles H. Pruett and Roger G. Wilkinson. Phys. Rev. 96, 1340-3 (1954) December 1.

Excited States of Ce^{140}. Herbert H. Bolotin, Charles H. Pruett, Paul L. Roggenkamp, and Roger G. Wilkinson. Phys. Rev. 99, 62-7 (1955) July 1.

Misalignments in the Michigan Radial Sector FFAG Accelerator. F.T. Cole, L.W. Jones, C.H. Pruett, and K.M. Terwilliger. MURA-203, November 1956.

Effects of Resonances in the Radial Sector FFAG Model. L.W. Jones, Charles H. Pruett, and Kent M. Terwilliger. MURA-212, December 1956.

Radio Frequency Experiment with an FFAG Electron Model Accelerator. K.M. Terwilliger, L.W. Jones, and C.H. Pruett. MURA-255, April 1957.

Experiments on Radio Frequency Knockout of Stacked Beams. L.W. Jones, C.H. Pruett, and K.M. Terwilliger. MURA-260, May 1957.

Electron Model Fixed Field Alternating Gradient Accelerator. F.T. Cole, R.O. Haxby, L.W. Jones, C.H. Pruett, and K.M. Terwilliger. Rev. Sci. Instr. 28, 403-20 (1957) June.

Beam Stacking Experiments in an Electron Model FFAG Accelerator. K.M. Terwilliger, L.W. Jones, and C.H. Pruett. Rev. Sci. Instr. 28, 987-97 (1957) December.

Studies of the Orbital Electron Capture Decays of Ce^{139} and Os^{185}. Charles H. Pruett. Ph.D. Thesis - Indiana University.

Comparison of Experimental Results with the Theory of Radio-Frequency Acceleration Processes in FFAG Accelerators. L.W. Jones, C.H. Pruett, K.R. Symon, and K.M. Terwilliger. International Conference on High Energy Accelerators and Instrumentation - CERN 1959.

Computer Studies and Experimental Measurements of Field Perturbations in the MURA Two-Way Electron Accelerator. G. Parzen, C.H. Pruett, W.A. Wallenmeyer, and D.E. Young. TID-7636 (p. 479-86).

Beam Experiments with the MURA 50 MeV FFAG Accelerator. C. D. Curtis, A. Galonsky, R.H. Hilden, F.E. Mills, R.A. Otte, G. Parzen, C.H. Pruett, E.M. Rowe, and M.F. Shea, D.A. Swenson, W.A. Wallenmeyer, and D.E. Young. Proceedings of the International Conference on High Energy Accelerators - Dubna, 1963, pp. 620-51.

Beam Extraction from the MURA 50 MeV FFAG Accelerator. F.E. Mills, G.M. Lee, H.K. Meier, J.E. O'Meara, C.H. Pruett, E.M. Rowe, C.A. Radmer, M.F. Shea, D.A. Swenson, and D.E. Young. Proceedings of the International Conference on High Energy Accelerators - Dubna, 1963, pp. 723-9.

MURA 50 MeV Electron Accelerator - General Description and Review I. F.T. Cole, G. Parzen, C.H. Pruett, W.A. Wallenmeyer, and D.E. Young. Rev. Sci. Instr. 35, 1393-7 (1964) November.

Design and Construction of the Magnets and Magnet Support Structure for the MURA 50 MeV Electron Accelerator-III. R.O. Haxby, E.A. Day, J.R. Mulady, C.H. Pruett, W.A. Wallenmeyer, and W.R. Winter, Jr. Rev. Sci. Instr. 35, 1402-8 (1964) November.

Magnetic Guide Field Measurements and Corrections in the MURA 50 MeV Electron Accelerator -VI. C.H. Pruett, R.S. Christian, G. del Castillo, R.O. Haxby, J.R. Mulady, R.A. Otte, G. Parzen, W.A. Wallenmeyer, and D.E. Young. Rev. Sci. Instr. 35, 1422-36 (1964) November.

Equipment and Procedures Used in Magnetic Field Measurements on the MURA 50 MeV Electron Accelerator-VII. J.R. Mulady, G.E. Bush, R.O. Haxby, C.H. Pruett, and W.A. Wallenmeyer. Rev. Sci. Instr. 35, 1437-44 (1964) November.

Measurements of the Properties of the Coherent Vertical Instability in the MURA 50 MeV Accelerator. R.A. Otte, H. Kamei, and C.H. Pruett. Bull. Am. Phys. Soc. 10, 457 (1965).

Electronic Feedback System for Damping the Coherent Vertical Instability in the MURA 50 MeV Electron Accelerator. C.H. Pruett, F.E. Mills, and R.A. Otte. Bull. Am. Phys. Soc. 10, 458 (1965).

Diagnostics and Control of a Coherent Instability in the MURA 50 MeV Electron Accelerator. C.H. Pruett, R.A. Otte, and F.E. Mills. Proc. Intern. Conf. High Energy Accelerators (Frascati, 1965).

Operation and Performance of the University of Wisconsin Physical Sciences Laboratory Storage Ring. E.M. Rowe, R.A. Otte, C.H. Pruett, and J.D. Steben. Paper B-36 presented at the U. S. Particle Accelerator Conference, Washington, D.C.. Transactions in Nuclear Science, 16, No. 3, p. 159-164 (1969).

Operation of an Electron Storage Ring as a Source of Synchrotron Radiation in the Vacuum Ultraviolet. C.H. Pruett, E.M. Rowe, R.A. Otte, and J.D. Steben. Bull. Am. Phys. Soc., Vol. 14, No. 1, p. 17 (1969).

CHARLES H. PRUETT
PUBLICATIONS (Cont'd.)

The University of Wisconsin Physical Sciences Laboratory Synchrotron Radiation Center Normal Incidence Monochromator. C.H. Pruett. 1970 University of Wisconsin Synchrotron Radiation Center Users Group Meeting (Abstract).

The Design of a 960 MeV Electron Storage Ring to Provide Synchrotron Radiation for XUV and Soft X-ray Spectroscopy. E.M. Rowe, C.H. Pruett, J.D. Steben, and W.R. Winter, Jr. Proceedings of the National Accelerator Conference, Chicago, Ill., p. 210, March 1-3, 1971.

Monochromator and Beam Line Development at the University of Wisconsin Physical Sciences Laboratory Synchrotron Radiation Center. C. H. Pruett. 1971 University of Wisconsin Synchrotron Radiation Center Users Group Meeting (Abstract).

Vacuum Ultraviolet Monochromator Developments at the University of Wisconsin Physical Sciences Laboratory. C.H. Pruett, N.C. Lien, and J.D. Steben. Conference Digest of 3rd International Conf. on Vacuum UV Radiation Physics, Tokyo, 1971, p. 31aA2-5. Proceedings of 3rd International Conf. on Vacuum Ultraviolet Radiation Physics, Tokyo, 1971.

XUV and Soft X-ray Instrumentation at the Synchrotron Radiation Center. C.H. Pruett. 1972 University of Wisconsin Synchrotron Radiation Center Users Group Meeting (Abstract).

An Ultrahigh Vacuum Monochromator for Synchrotron Radiation. F.C. Brown, R.Z. Bachrach, S.B.M. Hagstrom, N.C. Lien, and C.H. Pruett. IV International Conference on Vacuum-Ultraviolet Radiation Physics, Hamburg, Germany, July 1974.

New VUV Instrumentation at the SRC. C.H. Pruett, T.R. Winch, and E.M. Rowe. 1975 University of Wisconsin Synchrotron Radiation Center Users Group Meeting (Abstract).

VUV Optics and Monochromators. C.H. Pruett. Proceedings of the Synchrotron Radiation Facilities Quebec Summer Workshop, Quebec, Canada (1976).

Optical Systems Development at the Synchrotron Radiation Center - University of Wisconsin-Madison. C.H. Pruett. 1976 University of Wisconsin Synchrotron Radiation Center Users Group Meeting (Abstract).

CURRICULUM VITAE

December 1976

WALTER STEPHEN TRZECIAK:

Assistant Scientist, University of Wisconsin-Physical Sciences Laboratory.
Born December 27, 1941 in Chicago, Illinois. Married and has one child.
B. S. Physics, Illinois Institute of Technology, 1963.
M. S. Physics, University of Wisconsin, 1965.
Ph. D. Nuclear Engineering, University of Wisconsin, 1973

POSITIONS:

Graduate Assistant, Midwestern Universities Research Association - 1965 to 1967.
Research Associate, U. of Wis. Physical Sciences Laboratory - 1973 to 1974.
Assistant Scientist, U. of Wis. Physical Sciences Laboratory - 1974 to Present.

INTERESTS:

Particle accelerator technology, in general, and especially that related to electron storage rings and synchrotron radiation usage.

HONORS:

ΣΠΣ

PUBLICATIONS:

Longitudinal Space Charge Effects in RF Buckets, IEEE Transactions on Nuclear Science, NS-14, 3, 1967.

A "Wavelength Shifter" for the University of Wisconsin Electron Storage Ring, IEEE Transactions on Nuclear Science, NS-18, 3, 1971.

A "Wavelength Shifter" for the University of Wisconsin Electron Storage Ring, Ph. D. thesis, University of Wisconsin-Madison, 1972.

The Conversion of the NBS 180 MeV Electron Synchrotron to a 240 MeV Electron Storage Ring for Synchrotron Radiation Research, Proceedings of the 9th International Conference on High Energy Accelerators, SLAC, Stanford U., Stanford, Calif., May 1974.

Control of the Bunch Lengthening Phenomenon in Electron Storage Rings, Proceedings of the 9th International Conference on High Energy Accelerators, SLAC, Stanford U., Stanford, Calif., May 1974.

Design of the Storage Ring Source for the Ultraviolet, Proceedings of the Synchrotron Radiation Facilities Quebec Summer Workshop, Université Laval, Quebec, Canada, June 1976.

CURRICULUM VITAE

December 1976

PUBLICATIONS: (Cont'd.)

E. M. Rowe, M. A. Green, W. S. Trzeciak, and W. R. Winter, Jr., "An Advanced Electron Storage Ring System for Synchrotron Radiation Research," Fifth All-Union National Conference on Particle Accelerators, Dubna, USSR, Oct. 5-7, 1976.

Curriculum Vitae

John H. Weaver, Assistant Scientist

Date of Birth: September 16, 1946

Education:

University of Missouri-Kansas City	B. S.	1967	(Physics)
University of Missouri-Kansas City	M. S.	1969	(Physics)
Iowa State University	Ph. D.	1973	(Physics)

Professional Experience:

Postdoctoral Fellow	University of Missouri-Rolla	- 1973
Research Associate	Synchrotron Radiation Center, University of Wisconsin-Madison	- 1974
Assistant Scientist	Synchrotron Radiation Center, University of Wisconsin-Madison	- 1975
Associate	Ames Laboratory, USERDA	- 1975

Present Research Interests:

Optical properties of solids with emphasis on metals; photoemission and surface studies; modulation spectroscopy.

Membership in Professional Organizations:

American Physical Society
Sigma Xi

Association with other groups:

Collaborative studies performed in conjunction with SRC User Groups

Summer Schools, Institutes, etc.:

NATO Advanced Study Institute on "The Electronic Structure and Reactivity of Metal Surfaces," Namur, Belgium (Sept. 1975).

Quebec Summer Workshop on "Synchrotron Radiation Facilities," Quebec City, Quebec, Canada (June 1976).

Additional Activities:

Secretary, Design Group for the Aladdin/Tantalus 2.5 project.
Contributor to the resulting ERDA and NSF proposals.

Publications: See attached.

Publications:

1. J.H. Weaver, D.W. Lynch, and R. Rosei, "Optical Properties of Single-Crystal Zinc," Phys. Rev. B5, 2829 (1972).

2. D.W. Lynch, R. Rosei, and J.H. Weaver, "Infrared and Visible Optical Properties of Single-Crystal Ni at 4 K," Solid State Commun. 9, 2195 (1971).

3. J.H. Weaver and D.W. Lynch, "Low Energy Optical Absorption in ReO_3," Phys. Rev. B6, 3620 (1972).

4. J.H. Weaver, D.W. Lynch, and R. Rosei, "Optical Properties of Single-Crystal Be from 0.1 to 4.5 eV," Phys. Rev. B7, 3537 (1973).

5. J.H. Weaver, D.W. Lynch, and C.G. Olson, "Optical Properties of Nb from 0.1 to 36.4 eV," Phys. Rev. B7, 4311 (1973).

6. J.H. Weaver and D.W. Lynch, "Absorptivity of Single-Crystal Yttrium at 4.2 K," Phys. Rev. B7, 4737 (1973).

7. D.W. Lynch, R. Rosei, J.H. Weaver, and C.G. Olson, "Optical Properties of Some Alkali Metal Tungsten Bronzes from 0.1 to 38 eV," J. Sol. State Chem., 8, 242 (1973).

8. J.H. Weaver, D.W. Lynch, and C.G. Olson, "Optical Properties of V, Ta, and Mo from 0.1 to 30 eV," Phys. Rev. B10, 501 (1974).

9. R. Rosei, C.H. Culp, and J.H. Weaver, "Optical Transitions Involving the Fermi Surface in Ag: Experimental," Phys. Rev. B10, 484 (1974).

10. R.W. Alexander, R.J. Bell, C.A. Ward, J.H. Weaver, I.L. Tyler, and B. Fischer, "Possible Applications of Surface Electromagnetic Waves to Measure Absorption Coefficients," J. Chem. Phys., 59, 3492 (1973).

11. J.H. Weaver, R.W. Alexander, L. Teng, R.A. Mann, and R.J. Bell, "Infrared Absorption of Small Silicon Particles with Oxide Overlayers," Physica Status Solidi (a)20, 321 (1973).

12. E. Amrhein, N.J. Kreidl, D.E. Day, and J.H. Weaver, "Far Infrared Spectra of Polynary Chalcogenide Glasses," J. Non-Crystalline Solids 15, 526 (1974).

13. J.H. Weaver, C.A. Ward, G.S. Kovener, and R.W. Alexander, "Infrared Lattice Vibration Spectra of MnF_2," J. Phys. Chem. Solids 35, 1625 (1974).

Publications: (cont'd.)

14. D.W. Lynch, R. Rosei, and J.H. Weaver, "Infrared Absorption of Chromium-Rich Cr-Fe, Cr-Co, and Cr-Ni Alloys at 4.2 K," Physica Status Solidi (a) 27, 515 (1975).

15. J.H. Weaver, C.G. Olson, D.W. Lynch, and M. Piacentini, "Thermoreflectance of Mo from 0.5 to 35 eV," Solid State Commun. 16, 163 (1975).

16. J.H. Weaver, "Optical Properties of Rh, Pd, Ir, and Pt," Phys. Rev. B11, 1416 (1975).

17. D.W. Lynch, C.G. Olson, and J.H. Weaver, "Optical Properties of Ti, Zr, and Hf from 0.15 to 30 eV," Phys. Rev. B11, 3617 (1975).

18. D.W. Lynch, C.G. Olson, and J.H. Weaver, "Optical Properties of bcc and hcp Transition Metals," Proceedings IV International Conference on Vacuum Ultraviolet Radiation Physics (Pergamon Press, 469 (1975)).

19. J.H. Weaver, D.W. Lynch, and C.G. Olson, "Optical Properties of Crystalline W from 0.1 to 32 eV," Phys. Rev. B12, 1293 (1975).

20. J.H. Weaver and R.L. Benbow, "Low Energy Interband Absorption in Pd," Phys. Rev. 12, 3509 (1975).

21. J.H. Weaver and D.W. Lynch, "Anisotropic Optical Properties of Heavy-Rare-Earth Single Crystals," Phys. Rev. Letters 34, 1324 (1975).

22. J.H. Weaver, D.W. Lynch, C.H. Culp, and R. Rosei, "Thermoreflectance Studies of V, Nb, and Paramagnetic Cr," Phys. Rev. 14, 459 (1976).

23. J.H. Weaver, Editor, "Synchrotron Radiation Center Users Handbook."

24. E.M. Rowe and J.H. Weaver, "Synchrotron Radiation and Its Use in Modern Science," Scientific American, 1977.

25. J.H. Weaver and E.M. Rowe, "Synchrotron Radiation and Its Influence on Modern Science," Physics Teacher, 1977.

26. J.H. Weaver and C.G. Olson, "Optical Absorption in the 4d Transition Metals from 20 to 250 eV," Phys. Rev. B14, 3251 (1976).

27. J.H. Weaver and C.G. Olson, "Optical Absorption of hcp Yttrium," Phys. Rev. B15, (1977).

Publications: (cont'd.)

28. J.H. Weaver, "Low Energy Optical Absorption in α-U Metal," Phys. Rev. B (submitted).

29. J.H. Weaver, R.L. Benbow, and Z. Hurych, "Direct Emission from Multiplet Final States in Zr Observed by Ultraviolet Photoemission CFS Techniques," Solid State Commun. (submitted).

30. J.H. Weaver and C.G. Olson, "Interband Structure and the Role of the 5f Electron in Thorium: An Optical Investigation," Phys. Rev. B (submitted).

31. J.H. Weaver, C.G. Olson, and D.W. Lynch, "An Optical Investigation of the Electronic Structure of Bulk Rh and Ir," Phys. Rev. B (submitted).

32. J.H. Weaver and C.G. Olson, "Interband Absorption in hcp Scandium and Lutetium," Phys. Rev. B.

33. J.H. Weaver, C.G. Olson, and D.W. Lynch, "Anisotropic Optical Properties of the hcp Transition Metals Zr, Ru, Hf, Re, Os from 0.2 to 35 eV," Phys. Rev. B.

34. J.H. Weaver, D.W. Lynch and E. Colavita, "Low Energy Interband Structures in Fe and Co," Phys. Rev. B.

35. J.H. Weaver, D.W. Lynch, and D. Peterman, "Interband Absorption in the Ordered CsCl Structure of TiFe," Phys. Rev. B.

36. R. Bartlett, C.G. Olson, D.W. Lynch, and J.H. Weaver, "Optical Properties of the A15 Compounds Nb_3Sn and Nb_3Ge," Solid State Commun.

37. J.H. Weaver, "Soft X-ray Absorption in AlF_3," Solid State Commun.

38. J.H. Weaver and C.G. Olson, "Vacuum Ultraviolet Reflectivities and Soft X-ray Absorption in Sc, ScF_3 and YF_3," Phys. Rev. B.

39. J.H. Weaver, R.L. Benbow, and Z. Hurych, "UPS CFS Studies of the 4p-4d Transitions in YF_3," Solid State Commun.

40. M.A. Lind, J.L. Stanford, J.H. Weaver, and C.G. Olson, "Optical Investigation of Ordered Cr_2Al," Phys. Rev. B.

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41. J.H. Weaver and C.G. Olson, "Interpretation of the High Energy Interband Structures in the 4d and 5d Transition Metals," Phys. Rev. B.

42. J.H. Weaver and C.G. Olson, "5d-5f Transitions in the Soft X-ray Absorption of Th," Phys. Rev. B.

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1. J.H. Weaver, D.W. Lynch, and C.G. Olson, "Optical Properties of V, Nb, Ta, and Mo from 0.1 to 35 eV," American Physical Society Meeting, San Diego, March 1973.

2. C.H. Culp, J.H. Weaver, and D.W. Lynch, "Thermomodulation Spectra of V, Nb, and Ta at 310 and 90 K," American Physical Society Meeting, San Diego, March 1973.

3. D.W. Lynch, C.G. Olson, and J.H. Weaver, "Optical Properties of bcc and hcp Transition Metals," IV International Conference on Vacuum-Ultraviolet Radiation Physics, Hamburg, Germany, July 1974.

4. J.H. Weaver, "Optical Properties of Some Transition Metals," Instituto "G. Marconi", University of Rome, Italy, July 1974 (Invited).

5. J.H. Weaver, "Optical Properties of Rh, Pd, Ir and Pt, A Review," Seventh Annual Synchrotron Radiation Users Group Meeting, Stoughton, Wisconsin, October 1974.

6. J.H. Weaver, "Optical Properties of the Transition Metals," Univ. Wisconsin Solid State Seminar, Jan. 1975.

7. J.H. Weaver, C.G. Olson, and D.W. Lynch, "Optical Properties of Crystalline W," American Physical Society Meeting, Denver, 1975.

8. R.L. Benbow, Z. Hurych, and J.H. Weaver, "Electronic Structure of Layered Semiconductors Sb_2Te_3, Sb_2Te_2Se, and Bi_2Se_3," American Physical Society Meeting, Denver, 1975.

9. J.H. Weaver and C.G. Olson, "Optical Absorption in Y from 0.2 to 250 eV," Eighth Annual Synchrotron Radiation Users Group Meeting, Stoughton, Wisconsin, October 1975.

10. J.H. Weaver and C.G. Olson, "Soft X-ray Absorption in the 4d Transition Metals," American Physical Society Meeting, Atlanta, Georgia, March 1976.

11. J.H. Weaver, C.G. Olson, D.W. Lynch, R.L. Benbow, and Z. Hurych, "High Energy Interband and np-nd Absorption in the Transition Metals," Ninth Annual Synchrotron Radiation Users Group Meeting, Stoughton, Wisconsin, October 1976.

12. R.L. Bartlett, C.G. Olson, D.W. Lynch, and J.H. Weaver, "Optical Properties of Nb_3Ge and Nb_3Sn," Ninth Annual Synchrotron Radiation Users Group Meeting, Stoughton, Wisconsin, October 1976.

13. J.H. Weaver and C.G. Olson, "Interband Structure and the Role of the 5f Electrons in Thorium Metal," Ninth Annual Synchrotron Radiation Users Group Meeting, Stoughton, Wisconsin, October 1976.

CURRICULUM VITAE

December 1976

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Born in Milwaukee, Wisconsin, April 21, 1930. Married 1955 and has two children.
B. S. Mechanical Engineering, University of Wisconsin-Madison, 1956.

POSITIONS:

Midwestern Universities Research Association, Mechanical Engineer 1956-1958
Midwestern Universities Research Association, Chief Mechanical Engineer 1958-1968.
University of Wisconsin, Physical Sciences Laboratory, Project Administrator (Chief Engineer) 1968 to present.

ENGINEERING INTERESTS:

Vacuum System Design, Magnet Mechanical Design, Heat Transfer, Cryogenics (including refrigeration systems, and design of vessels operating at cryogenic temperatures).

CONSULTING ACTIVITY:

Argonne National Laboratory - Design of Vacuum Chamber for Zero Gradient Synchrotron.
National Accelerator Laboratory - Mechanical Design of Magnets and Vacuum Chamber for 200 BeV Accelerator.

PAPERS:

The MURA 50 MeV Electron Accelerator Design and Construction, R.S.I., pp 1393-1482, Vol. 35, No. 11, Nov. 1964.

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APPENDICES

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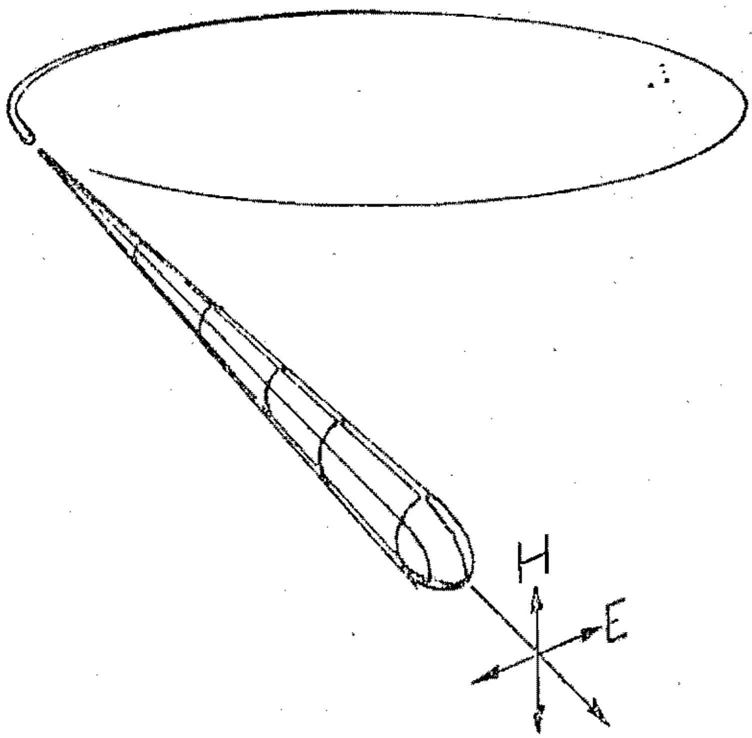
THE UNIVERSITY OF WISCONSIN-MADISON - PHYSICAL SCIENCES LABORATORY

SYNCHROTRON RADIATION CENTER

January 1974 - October 1976



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D. E. Eastman, J. L. Freeouf, G. W. Rubloff, W. Gudat, and G. M. Bancroft, "Photoemission and Optical Spectroscopy Studies Done at the Synchrotron Radiation Center - University of Wisconsin-Madison."

F. C. Brown, "The Silicon L-Edge."

M. Piacentini, A. Balzarotti, E. Burattini, D. W. Lynch, and C. G. Olson, "Far Ultraviolet Reflectivity of Layer Compounds GaSe, InSe, GaS."

L. C. Lee, "Observation of Rydberg States of CH_4, CF_4, SF_6, and CF_3Cl in $\lambda\lambda$ 550-680 Å."

J. W. Taylor, A. H. Grange, and K. V. Wood, "New Measurements of Photoabsorption and Photoionization Cross Sections and Their Use for Supersonic Molecular Beam Mass Spectrometer Calibration."

P. C. Kemeny, J. A. R. Samson, and A. Starace, "Measurement of the Xenon σ 3/2 : σ 1/2 Branching Ratio Within the Xe 5s $5p^6$ 6p ($^1P_1$) Resonance."

R. J. Bartlett, C. G. Olson, D. W. Lynch, and J. H. Weaver, "Optical Properties of Nb_3Ge and Nb_3Sn."

G. M. Bancroft, W. Gudat, and D. E. Eastman, "Photoemission Studies of Atomic and Final State Effects on the Pb 5d Core Level Cross Sections Using Synchrotron Radiation."

J. H. Weaver and C. G. Olson, "The Role of the 5f Electrons in the Optical Properties of Thorium."

Appendix II

Microminiaturization in Semiconductor Device Processing

One of the most important areas of future development of semiconductor device technology is in miniaturization of integrated circuits. Because this involves dimensions possibly as small as 100 Å, it requires major steps in process development as well as an improvement in understanding of materials behavior and physical processes at such small dimensions. Among the particular problems to be attacked are 1) mask making, 2) mask transfer and exposure, 3) photochemistry of resists, 4) materials characterization and physics and chemistry of surfaces and interfaces, and 5) processing and device fabrication.

We are proposing, through a cooperative effort between the Materials Science Center, the Synchrotron Radiation Center, and the Integrated Circuits Laboratory at the University of Wisconsin-Madison, a coherent research and development effort in microminiaturization.

Materials Science Center

The Materials Science Center at the University of Wisconsin-Madison was developed to foster and coordinate interdisciplinary materials research. The Center has made it possible to assemble in a coherent fashion a wide array of state-of-the-art analytical instruments that are widely used by a number of research groups, resulting in several strong interdisciplinary research projects.

About 25 faculty members from Chemistry, Physics, and Engineering departments are associated with the Center. Projects range from studies of adhesion of polymers to electronic properties of semiconductors and from device processing to surface physics.

Equipment available in the Center of pertinence to microminiaturization include a scanning electron microscope and microprobe, Auger spectroscopy, ESCA, and a variety of optical techniques, evaporation facilities, and sample preparation support facilities. An ion implanter is also available.

Synchrotron Radiation Center

SRC is a most important component in the microminiaturization research effort, in that it provides the source of radiation for exposure of photoresist. Although it is possible to use the present storage ring (in fact, demonstration experiments to that effect have been carried out), the proposed Aladdin storage ring will be much more suitable for this effort, in that it provides a more intense source of radiation at the proper wavelength for photoresist exposure. The use of synchrotron radiation is detailed below under "Experiments".

Integrated Circuits Lab

The third major component of the microminiaturization effort is the IC Lab, for carrying out the diffusion and processing of samples. The IC Lab is recognized as one of the best in the country. The present mask-making facility is associated with the IC Lab, and improvements in mask-making will originate from this base.

Experiments

1. Demonstration Experiment

   A demonstration experiment in making a fine-line mask and exposing it on the existing storage ring is planned in the near future. It involves using preferential - etch techniques to cut a 200 Å line into Si and using this as a mask to expose photoresist deposited on another piece of Si. Calculations indicate that it should easily be possible to make simple masks by etching and exposing them with synchrotron radiation. Exposure times with the present ring are relatively long, but will be significantly reduced using Aladdin.

   Participating Faculty:

H. Guckel	Electrical and Computer Engineering
M. G. Lagally	Metallurgical and Mineral Engineering
E. M. Rowe	Synchrotron Radiation Center
J. H. Weaver	Synchrotron Radiation Center

2. Photochemistry of Polymers

   In order to develop a workable process, considerable information is required about the behavior of photoresist under strong radiation conditions and for very small dimensions. It is planned to study the behavior of typical photosensitive polymers using synchrotron radiation. It would naturally be desirable to use optimum intensity and wavelength. These will be available in Aladdin. However, preliminary experiments are planned on Tantalus.

   Participating Faculty:

S. Cooper	Chemical Engineering
H. Guckel	Electrical and Computer Engineering
E. Rowe	Synchrotron Radiation Center

3. Physics and Chemistry of Interfaces/Materials Characterization

At the small dimension involved here, surface properties may become exceedingly important to the operation of a device. In fact, the surface effects may dominate. We plan to study surface and interface effects in Si and at the SiO_2/Si interface in the presence of typical dopants. We expect to make electrical measurements on samples on which simple fine-line patterns have been etched. Analytical tools to be used include Auger spectroscopy, ESCA, ultraviolet photoemission spectroscopy using synchrotron radiation, and photoconductivity, as well as more standard electrical measurements.

Participating Faculty:

M. G. Lagally	Metallurgical and Mineral Engineering
R. N. Dexter	Physics
J. D. Wiley	Electrical and Computer Engineering
Henry Guckel	Electrical and Computer Engineering

4. Processing and Device Fabrication

In the final analysis, the purpose of these studies is to produce a useable device. This involves mask-making, mask transfer, diffusion, oxidation and metallization, and device testing. These experiments will be carried out in conjunction with the IC Lab, using the scanning electron microscope available in the Materials Science Center. Efforts will be concentrated on making single-mask devices such as Josephson junctions.

Participating Faculty:

H. Guckel	Electrical and Computer Engineering
J. Nordman	Electrical and Computer Engineering

<u>Summary</u>

It is clear that in this multifaceted attack on development of a useable microminiaturization process, the availability of a synchrotron source of the proper intensity and wavelength is a necessity. Although preliminary experiments can be performed on the present source, the proposed new ring would greatly aid in carrying out this program.

Description of Possible Data Acquisition System at the Expanded SRC

Users of SRC could often use on-line data acquisition services; however, reliability and ease of use are prime concerns. Users traveling from a distance present a major problem, because interfacing to almost any computer system, both from the hardware and software viewpoint, takes time. This time constraint leads to the concept of small computer systems which can be loaned to users for a few weeks or months before the users come to SRC. Initially, there would be three to five of the following small systems:

1. A microcomputer with about 16 K words of memory. This computer would be an imitation of a larger minicomputer, and therefore would have available to it an operating system, FORTRAN, BASIC, etc.

2. A mass storage device, either a floppy disc or a small tape cartridge. Floppy discs are faster than tapes, but they are less reliable for program development use and have limited capacity. Thus, a cartridge may be preferred. Two drives may or may not be needed.

3. An I/O capability which can at least read ASCII at various baud rates. At least two devices (Teletype and a line from the experiment) would be needed.

4. The ability to drive an x-y plotter, pulse a monochromator, and possibly read a scaler in binary. (Other interfaces with equipment would probably be in ASCII or possibly via CAMAC.)

Users would be expected to provide Teletypes (SRC has some available), x-y plotters, and an ASCII interface to their experiment. The ASCII interface should probably be at least 30 characters per second (300 baud), since Teletype speeds (10 cps or 110 baud) are very slow. SRC would provide a library of subroutines and driver programs which users could adapt to their own experiment, putting together simple programs on their loaned system.

In order to develop a library of programs for the small systems, SRC would need a larger system for extensive program development. While cartridges and floppy discs are good for data storage, they tend to be slow or break down when used heavily for program development. Therefore SRC should have the following moderate size system:

1. The larger minicomputer upon which the microcomputer is modeled (so that all software for the systems is compatible) with about 32 K words of memory.

2. The same small mass storage device (either floppy or cartridge) which the small systems have, in order to communicate with these systems.

3. A good sized disc drive, 9-track tape drive, and line printer. Perhaps also some graphics capability.

4. Possibly a network software package which would allow the microcomputers to use the larger system's mass storage devices when running at SRC, instead of their own cartridges or floppy discs.

These requirements could be met easily by accelerator control computer during stored beam periods when the computer is operating in the monitor mode or when the storage ring is off (possibly eight to twelve hours per day).

The small systems would be the property of SRC; however, users could purchase equivalent systems, probably through SRC, if they wanted to keep their own system at home on a permanent basis. SRC would be able to supply its library of subroutines and sample drivers to users who purchased such a system through SRC. Users would not want to do extensive program development on a minimal system, but they could piece together a program from SRC-supplied software without a large programming effort.

The larger system at SRC would be available to both SRC staff members and SRC users, both for program development, data reduction, and transferring data to 9-track tape.

It will be necessary to establish a standard hardware and software interface to any data acquisition system. This proposal specifies ASCII output from and input to experimental apparatus as a standard. A CAMAC interface may be provided in addition. It may even be preferable to establish a different type of standard, possibly based on an interface supplied by PSL. Further investigation in this area is needed.

Users wishing to use multi-channel analyzers with this system should be able to do so using an ASCII interface. Users wishing to use an interrupt feature or a real time clock should be able to do so. Users with high data rates may find the small system too slow, especially if they use an ASCII interface.

Programming would be in either FORTRAN or BASIC or both. BASIC, an interpreter, provides more immediate, interactive control over an experiment. FORTRAN, besides being more familiar, is a lot faster than BASIC. It may be fairly easy to write library subroutines so that they can be called by either FORTRAN or BASIC.

Since each user would have his own system, hopefully real time response would be adequate. Simultaneous data acquisition and simple analysis should be possible, but the time constraints imposed by a microprocessor and an ASCII interface may limit data rates. BASIC would further reduce the throughput capacity. A non-ASCII interface (either CAMAC or some other) would greatly increase throughput.

Reliability of an individual system is provided by having more than one small system available at SRC, for backup purposes. However, only one larger system would exist.

Price estimates for the two systems follow on the next page.

There are six vendors who are likely candidates for the kind of dual system proposed here. They are:

Data General
Digital Equipment
Hewlett Packard
Interdata
Modcomp
Texas Instruments

Prices from these vendors (9/1/76) for a packaged microcomputer run about $5,500 to $10,000, with the $10,000 system from DEC including D to A's, A to D's, floating point hardware, and real time clock. A dual drive floppy is uniformly about $4,000 extra. (The first price does not include a disc)

Prices for the larger system (e.g. Interdata 7/32) start at about $25,000, with console and disc. A character line printer will be about $3,500, a nine track tape drive about $10,000.

Networking software, available for $1,000 to $2,000 from some vendors, could make floppy discs at the site unnecessary, and thus reduce costs by a couple multiples of $4,000.

Software is included in the price of some systems, but the less expensive systems will generally have software priced separately. FORTRAN and BASIC run about $2,000 apiece, when they are priced separately, but only one copy need be bought for all systems.

Care must be taken in selecting a system, because the cheaper systems have greatly reduced capability; some cannot compile FORTRAN, for instance. Thus it will probably cost at least $7,000 for an appropriately packaged microcomputer, plus about $4,000 for a dual floppy disc drive. The larger development system would be about $50,000 minimum (including printer and tape unit and software).

Appendix IV

A. Beam Line and Instrumentation Costs for Aladdin

The cost of instrumenting Aladdin with an initial complement of 14 monochromated beams can be rather inexpensive if instruments and components from Tantalus I are used for all of the implementation. On the other hand, if all new instrumentation is used, costs will be quite a bit higher. The optimum choice of instrumentation will lie somewhere in between these two extremes. Some of the instruments on Tantalus I are specifically designed for use on that machine and will need some modification for optimum performance when used on Aladdin. Some other instruments (primarily the older commercial instruments) are poor vacuumwise and should also be modified. In view of the total instrument complement needed to carry out the scientific objectives of Aladdin, it may not be as cost effective as it now appears to carry out these modifications on obsolescent or specialized instruments.

Therefore, we have explored an alternative to simply transplanting all of the instrumentation and beam lines presently set up at Tantalus I to Aladdin. This plan calls for upgrading eight of the fourteen instruments and beam optics systems from Tantalus I and acquiring six new monochromators and beam optics systems designed specifically to exploit the improved characteristics of Aladdin. It is expected that this work would be funded through an additional grant and carried out in parallel with the Aladdin construction program. With the exception of the grazing incidence and toroidal instruments, the monochromator prices are estimates from a commercial vendor (GCA-McPherson).

The main needs for Aladdin instrumentation that cannot be met with instrumentation from Tantalus I are for several high resolution instruments for the 500 eV to several keV region, an additional 3 or 4 meter high resolution normal incidence monochromator, and an additional high resolution near grazing incidence toroidal grating monochromator. In addition, two vertically dispersing 1 meter normal incidence monochromators could make good use of the optimized properties of Aladdin at longer wavelengths.

The current price for a commercially manufactured ultrahigh vacuum version of a 3 meter normal incidence monochromator is $85,000 without pumping or gratings which would add about $8,000 to the price. The two 1 meter vertically dispersing normal incidence monochromators will cost about $60,000 each without pumping system and grating. These will add about $14,000 to the cost for two of these instruments. The very short wavelength grazing incidence monochromator still requires development but it is estimated that they would cost about $80,000 each, complete with grating and pump. Similarly, the toroidal grating monochromator is not completely designed but a cost of $55,000 for this instrument, complete with gratings and pumping system, appears reasonable at this time.

It will be noted that transmission grating monochromators have not been mentioned here. The reasons for this omission are made clear in the next section of this appendix.

Components for about eight beam lines could be brought over to Aladdin from Tantalus I with only minor modifications required. New beam lines will cost about $30,000 each on the average for the optics, vacuum system, support stands and adjustments, etc.

A summary of costs is given in the Table.

Table I. Estimated Costs for Improved Aladdin Instrumentation

Cost of upgrading and reconditioning Tantalus I beam lines for use on Aladdin (need all metal manual valve, fast acting valve, bakeout system, etc.) @ \$5,000	\$ 40,000
Cost of new beam lines (optics, vacuum system, support stands, adjustment system, bakeout, etc.) @ \$31,000	\$186,000
3 Meter vertically dispersing normal incidence monochromator complete with pumping system and gratings	\$ 93,000
Two 1 Meter uhv vertically dispersing monochromator complete with pumping system and gratings @ \$66,000	\$132,000
Two high resolution short wavelength grazing incidence monochromators @ \$80,000	\$160,000
One toroidal grating grazing incidence monochromators	\$ 55,000
Total for 14 monochromatic beam lines (with 8 from Tantalus I)	\$666,000
Calibration, alignment, and grating testing equipment	\$ 25,000
TOTAL	\$691,000

B. Considerations of Monochromators for Use in the 10 Å Region on Aladdin

The wavelength region around 10 Å is a very difficult one for high-resolution monochromators that are to be used with storage ring synchrotron radiation sources and massive sample chambers. At wavelengths less than about 4 Å nondeviating, double channel-cut silicon or germanium crystal monochromators can be used with good resolution ($> 10^5$) and high efficiency. For wavelengths greater than about 4 Å there are no crystals available at the present time with large atomic plane spacings, high efficiencies, and the properties necessary to produce good channel-cut crystal monochromators.

Quartz crystals have been used in a bent-crystal, focusing monochromator with $A\ell$-K_α radiation (8.3 Å, 1.5 keV) with a resolution of about 0.2 eV and a reflection efficiency of 30%[20]. With four reflections in a double-cut configuration the system efficiency using quartz would be only about 1%. Discrete wavelengths can be produced with focusing crystal monochromators, but the Bragg condition requires that the entrance and exit beams be symmetrical about the crystal normal and that the slits lie on the Rowland circle. This makes scanning nearly impossible when a large sample chamber is involved. Therefore, for the foreseeable future, we must consider diffraction grating monochromators for high resolution scanning applications in the 10 Å region.

Before evaluating the various types of diffraction grating monochromators we have to determine the magnitude of the resolution that we should try for. Among the experiments requiring the highest resolution are ESCA, XPS, measurements of line widths and relative intensities of lines in absorption and chemical shifts are in the range from 0–10 eV with many having magnitudes of a few tenths of an eV. Also some XPS structures and line widths are of the order of 0.5 eV. Therefore, it appears to be desirable to be able to resolve 0.1 eV or better.

There are three types of gratings to be considered for use: concave reflection gratings, plane reflection gratings, and transmission gratings. Concave reflection gratings have been used down to ~ 1 Å and modern techniques are capable of producing fairly efficient gratings. Concave gratings produce their own focusing and in a Rowland circle mount no other optics are required between the slits of the monochromator. In addition, a spherical optical surface can be produced with greater accuracy than any other. In general, however, Rowland circle mounts in the grazing incidence region are complicated, expensive, and, when in a nondeviating configuration, require other reflecting surfaces outside the slits. Plane reflection gratings can be used with very simple scanning systems since only a simple rotation is required, but other focusing optics must be used to focus the diffracted beam on the exit slit and sometimes to collimate the beam before the grating. In addition, at large angles of incidence, the scanning range of a plane grating monochromator is small due to occulting of the incident or exit beam as the grating is turned unless auxiliary mirrors permit several optical paths to be used. Transmission gratings for the soft x-ray region are still in the experimental stage[21], but they are of great interest since there is no absorption of the radiation that passes through the slots in the grid and, therefore, their efficiencies should be fairly high.

Since transmission gratings are new let us first consider using them for a 10 Å, 0.1 eV ($E/\Delta E = 12,400$) resolution monochromator.

There are four factors which influence the resolution of a plane grating monochromator regardless of whether the grating is used in reflection or transmission. They are:

1. The number of lines illuminated by the photon beam.
2. The divergence of the incident photon beam at any given point on the grating surface.
3. The dispersion of the grating used.
4. The quality of the mirrors used to collimate the beam and (or) focus the diffracted radiation on the exit slit of the monochromator.

As we shall see, items 2, 3, and 4 are the limiting factors in providing high resolution at high energies with a transmission grating.

As is well-known, the resolution of a plane grating illuminated by parallel rays of light is given by:

$$R = nN$$

where n is the spectral order number and N is the number of lines illuminated. The number of lines illuminated is, of course, the number of lines per millimeter of the grating times the width in millimeters (perpendicular to the grating lines) illuminated by the light beam. The present state-of-the-art can produce gratings with about 3600 1/mm (grating spacings of about 2800 Å). Therefore, we need to illuminate only about 4 mm of grating width to have $R > 12,400$. As the number of lines per millimeter increases, the ratio of radiation scattered from the edges of the openings to diffracted radiation will also increase and experimental measurements will be required to determine how useful high line density gratings will be.

The effect on the resolution of an angular spread in the beam incident on a plane transmission grating can be calculated from the expression:

$$\Delta\lambda = \Delta\alpha \cdot d/n \cdot \cos\beta$$

where d is the grating spacing, n is the order number, and $\Delta\lambda$ is the wavelength spread of radiation diffracted at a given angle when the radiation incident on each point of the grating contains an angular spread $\Delta\alpha$. This angular spread comes from imperfect collimation of the incident beam due to finite source size, finite source to grating distance, and imperfect optical surfaces in any collimating optics that are used. Aladdin has $4\sigma_y = 220$ μm and a full vertical angle at 10 Å equal to 0.8 mrad. If we wish to reduce the number of reflecting surfaces to a minimum, we can illuminate the grating directly. Using the central 0.4 mrad of beam we can fill 4 mm of grating width at 10 meters. At 10 meters from the grating, the 220 μm high beam subtends $\Delta\alpha$ = $(220 \times 10^{-6})/10 = 2.2 \times 10^{-5}$ radian. If we have a 3600 ℓ/mm grating (d = 2800 Å) at normal incidence (n = 0), we have that $\Delta\lambda = 0.062$ Å in first order. However, to have $\lambda/\Delta\lambda = 12,400$ at 10 Å, should be 8.1×10^{-4} Å. Even an entrance slit and collimating optics cannot reduce $\Delta\alpha$ to the necessary 3×10^{-7} radian in order to have $\Delta\lambda = 8 \times 10^{-4}$ Å because even the best x-ray telescope mirrors have angular accuracies of about 1 sec of arc ($\sim 5 \times 10^{-6}$ radian).

We see that if we increase α so that β increases we achieve the required $\Delta\lambda$ at a larger $\Delta\alpha$. However, we need to go to $\alpha \approx \beta \approx 89^{\circ}$ before we can use angular spreads of 10^{-5} radian and we have a reflection grating rather than a transmission grating.

Having ruled out the possibility of achieving 0.1 eV resolution at 10 Å with a transmission grating let us consider reflection gratings. If we let $\alpha \approx \beta \approx 89^{\circ}$, we have that for $\Delta\lambda = 8 \times 10^{-4}$ Å and d = 2800 Å it follows that $\Delta\alpha = 1.64 \times 10^{-5}$ radian. If we place a 100 μm slit near the beam it will subtend 1.64×10^{-5} radians at about 6 meters. A 100 mm long plane grating at $\alpha = 89^{\circ}$ will intercept a 1.75 mm beam height (which is about 0.3 mrad) at 6 meters or about 45% of the beam. If we can put about 10 horizontal mrad of beam on the grating we would have 2.4×10^{11} photons/sec in E = 0.1 eV at 12,400 eV for a 100 mA beam in Aladdin. If we have a 5% grating efficiency and about 50% efficiency for the mirror which focuses the beam on the exit slit, we would have $2.4 \times 10^{11} \times .45 \times .05 \times .5 = 2.7 \times 10^{9}$ photon/sec in $\Delta E = 0.1$ eV. A state-of-the-art grazing incidence mirror system would be adequate to focus the beam on the exit slit.

Let us now consider what can be done with a concave grating in a Rowland circle mounting. Since the bandpass of a Rowland circle mounting is given by:

$$\Delta\lambda = \frac{d \times \Delta s}{R}$$

where R is the radius of curvature of the grating and Δs is the slit width, we see that we need a grating with small grating spacing and large radius of curvature to get high resolution. J-Y Optical Systems, Inc. has a grating listed with R = 11.573 meters and 3600 1/mm (d = 2778 Å). These parameters and a bandpass of 8×10^{-4} Å give a slit width of 3.3 μm. With $\alpha \approx \beta \approx 89^{\circ}$, central image will be 40.4 cm from the entrance slit. At 10 Å in first positive order the distance from the grating to the exit slit becomes 1.00 meter. If we allow a maximum of 3 meters between entrance and exit slit and maintain $\alpha = 89^{\circ}$ we could reach 70 Å (177 eV). Conceptually, the monochromator would consist of an entrance slit module, an exit slit modeule, and a grating scanning mechanism module set up in an arrangement similar to a precision optical bench. The scanning module would be able to traverse the grating along about 5^0 of arc of the Rowland circle. To cover the full range of wavelengths between 10 Å and 70 Å, the modules would have to be relocated in several different relative positions.

With the above grating and $\alpha = 89^0$ the optimum width of the grating (for straight, equally spaced grooves) is 30.8 mm at 10 Å. This grating length will subtend 2.7 mrad at the entrance slit. About 58% of the beam is within .4 mrad. If this is matched into the 2.7 mrad angular acceptance of the grating with a 0.15 magnification mirror system the beam spot on the slit plane will be about 33 μm high (4 σ_y) and the slit will accept 0.4 σ_y. Fifty percent of the gaussian distribution is within 1.35 σ_y so about 20% will be within 0.4 σ_y. Again, if we can put 10 mrad of horizontal beam spread into the monochromator we will have 2.4×10^{11} photons/sec in $\Delta E = 0.1$ eV at 1,240 eV for a 100 mA beam in Aladdin. If we have a 5% grating efficiency and two reflections at about 50% efficiency we have $2.4 \times 10^{11} \times .2 \times .05 \times .25 = 6 \times 10^8$ photons/second in a 0.1 eV bandwidth. This is about a factor of 4 less than the plane grating "super grazing" monochromator.

We conclude that the plane grating monochromator looks the most attractive from the standpoints of greater throughput, more versatility, and the possibility of covering a larger scanning range with reflective filtering as is done with the Flipper monochromator at DORIS.

It should be noted here that the beam height in Super Aladdin will be .068 mm (4 σ) and, therefore, the performance of both grating instruments described here can be considerably improved.