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SYNCHROTRON RADIATION RESEARCH FACILITY

CONCEPTUAL DESIGN REPORT

PROJECT NO. 78-CH-004

June 1976

MASTER

BROOKHAVEN NATIONAL LABORATORY
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PURPOSE

The purpose of this Report is to define, in general outline, the extent and proportions, the type of construction, the schedule for accomplishment, and the estimated cost for a new Synchrotron Radiation Facility, as proposed to the Energy Research and Development Administration by the Brookhaven National Laboratory. The Report is concerned only indirectly with the scientific and technological justification for undertaking this project. The latter is addressed explicitly in separate documents (the Schedule 44 and a proposal book). The Report does consider user requirements, however, in order to establish a basis for design development. Preliminary drawings, outline specifications, estimated cost data, and other descriptive material are included as supporting documentation on the current status of the project in this pre-construction phase.

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APPENDIX

I. INTRODUCTION

This project will provide a national dedicated facility for multidisciplinary research with synchrotron radiation, a powerful investigative tool of major importance for the materials, molecular, and life sciences. The facility is proposed not only because of its value for fundamental research in these broad areas, but also because of its importance for experimental and diagnostic investigations directly relevant to practical energy and environmental concerns of the nation.

There are several characteristics of the synchrotron light emitted from an electron storage ring which make it uniquely useful to many classes of research. The spectrum is continuous, with radiation produced at wavelengths either not available from other sources or available only at feeble intensity. The intensities achievable are exceptionally high, and since the emission occurs from a very small volume and is highly collimated, the source is extremely bright. Further, beams are stable in position and intensity, and are highly polarized. Photons are emitted in nanosecond width pulses with separations between pulses of a few tens of nanoseconds up to about a microsecond. This time structure can be exploited for the study of dynamical properties and kinetic processes. Finally, electromagnetic radiation is emitted from all curved regions of the electron orbit, and thus many photon users may be accommodated simultaneously.

Both in this country and abroad, however, scientific and technological investigations using synchrotron radiation have been limited by the characteristics of presently available sources. The few existing facilities dedicated solely to this research are small and provide spectra extending from long wavelengths only to the far ultraviolet. Those sources which can furnish photons at x-ray wavelengths were designed for

and have been used mainly for high energy physics, with serious attendant shortcomings for synchrotron radiation utilization. Moreover, many of these sources are synchrotrons and do not have the beam stabilities provided by a storage ring. Thus, it has been widely recognized that there is an urgent need for specially designed facilities intended exclusively for research with synchrotron radiation.

The design approach for the proposed Brookhaven facility evolved from an interdepartmental study initiated at the Laboratory in 1971, along with extensive and continuing contact with outside members of the potential user community. It was concluded that user requirements could be met most effectively by incorporating two storage rings in a single facility operation. With this approach it was then possible to develop a conceptual design optimizing optical characteristics for x-ray users in one ring, and for users of vacuum ultraviolet (VUV) radiation in the other. The rings are designed for flexible operation over electron energy ranges extending above 2 GeV in the x-ray case, and up to 700 MeV for the VUV. Each ring is designed for operation with circulating currents approaching 1 ampere.

An overall layout of the facility is shown in Figure 1. Electrons are injected from a 50 MeV linear accelerator into a 700 MeV booster synchrotron. Surrounding the linac and booster is the 2 GeV ring; injection takes place in one of the long straight sections of the large ring. The small 700 MeV storage ring, located nearby, is served by the same injection system.

FIGURE 1
OVERALL FACILITY LAYOUT

II. DESIGN BASIS

A. The Synchrotron Radiation Spectrum

Relativistic electrons travelling in a curved path in a magnetic field emit electromagnetic radiation covering a very broad spectrum. The radiation pattern is strongly peaked in the forward direction, coming off approximately tangentially to the curved electron orbit. At any moment the radiation from an electron is contained in a cone of rms halfwidth approximately $1/\gamma$ radians, where γ is the ratio of mass to rest mass of the electron. The radiation is strongly polarized, the degree of polarization varying with angle within the radiation cone. It is emitted from a very small source, of the order of mm^3 in volume.

Intensity as a function of wavelength and angular distribution of the synchrotron radiation is conveniently expressed in terms of a characteristic wavelength,

$$\lambda_c = 4\pi\rho/3\gamma^3$$

or

$$= 3.50 \rho/E^3 = 186/BE^2$$

with the wavelength in $\text{\AA}$ units, the radius of orbit curvature ρ in m, the magnetic field in kilogauss, and the electron energy in GeV.

At the large values of γ appropriate for the GeV range of electron energies of concern here,

$$\gamma = 1957 E .$$

Similarly, the energy is nearly proportional to momentum and the magnetic rigidity can be approximated by

$$B\rho = 33.35 E .$$

A useful intensity vs. wavelength function is the number of photons emitted in all vertical angles per $\Delta\lambda$ for constant resolution

($k = \Delta\lambda/\lambda$). If $N_k(\lambda)$ is the number of photons emitted per (sec, ma of electrons, m-rad of circular arc, $k\lambda$ in Å)

$$N_k(\lambda) = k \gamma F_2 (\lambda_c/\lambda)$$

where F_2 is a function only of λ_c/λ . Thus if a value of λ_c is set by adjusting both E and B, the flux per $k\lambda$ will be proportional to γ (i.e. E).

The number of photons per m-rad of vertical angle, ψ , at $\psi = 0$ and per sec, ma, m-rad of arc, $k\lambda$ is

$$N_k(0, \lambda) = k\gamma^2 F_1 (\lambda_c/\lambda) .$$

For a set value of λ_c the flux per unit vertical angle will then vary as γ^2 .

The functions F_1 and F_2 are shown plotted vs. λ/λ_c in Figure 2, together with spectral distribution plots (N_k/λ) vs. λ) for various combinations of E and B. Normalized angular distributions of the linearly polarized components of radiation for various values of λ/λ_c are shown in Figure 3. The abscissa is $\gamma\psi$ and so for a set λ/λ_c the angular distribution will shrink with increasing γ . In Figure 3, 100% is equal to $N_k(0, \lambda)$. It is apparent that experiments making direct use of the polarization should be carried out near λ_c for best conditions.

FIGURE 2
FLUX vs. λ WITH $k = \Delta\lambda/\lambda = 0.001$; F_1 AND F_2 vs. λ/λ_c

FIGURE 3
ANGULAR DISTRIBUTIONS OF
LINEARLY POLARIZED COMPONENTS

Since the flux in all vertical angles is proportional to E for a fixed value of λ/λ_c , and per unit vertical angle is proportional to E^2 , it might seem at first sight that the design energy of a storage ring should be set at the highest feasible value. Rf power in the range of hundreds of kilowatts to megawatts must be considered, however, and it is not a trivial matter either to generate or to dissipate it. (The users will typically employ radiation from 10° or so of the magnetic bend, leaving the radiation from the remaining 350° to be absorbed by water cooling.) The total energy radiated by an electron per revolution around a ring is

$$E_T(\text{KeV}) = 88.5 E^4/\rho \text{ (GeV}^4/\text{m) .}$$

For I amps circulating the total radiation power, which is also the rf power that must be supplied continuously, is

$$88.5 I E^4/\rho \text{ kw .}$$

Note that the radius of curvature of the orbit ρ is proportional to E/B , so that the rf power is proportional to $E^3 B$. Since λ_c is inversely proportional to $E^2 B$, it is more economical in power to decrease λ_c by increasing B rather than E .

From a user's point of view, the important questions relating to radiated power are how much represents a gain in useful photon flux for his experiments and how much is just creating problems in optical element design and location and in unnecessary background. The radiation beam sweeps out a thin sheet with emission in a vertical semi-angle of $\sim 1/\gamma$

and the power density in this beam can be very large. An approximation of power per unit area, useful for estimating, is

$$P/A = 1.4E^5/\rho D^2 \text{ kw/cm}^2 \text{ amp}$$

where D is the distance in m from the source. At several GeV, and moderate current levels, the flux can be so high that no optical element can survive very near the source. The percentage of radiation power at wavelengths greater than λ is shown in Figure 4 as a function of λ/λ_c . Users working in the UV clearly need a long λ_c spectrum in order to avoid the powerful x-ray contamination accompanying a short λ_c .

B. Optical Characteristics

A synchrotron light source is a specialized single-beam electron storage ring. Alternating-gradient focussing coupled with available technology permits wide latitude in the design of a storage ring, but one must make choices which balance performance against cost and complexity. Since this source is proposed for diversified research in spectroscopy, the characteristics of the electron beam are important primarily as they affect the properties of the emitted radiation. This introduces quite different considerations from those involved in a design for high energy physics. One is not only concerned with obtaining high photon fluxes over appropriate spectral distributions, but the quality of the electron beam as a bright optical source also becomes very important. In addition, the design geometry must be adapted to emerging light pipes and to the optical element and spectrometer configurations desired by users.

A designer is not limited to arc bending magnets for providing optical sources. Use can also be made of moderately long insertions, sometimes called long straight sections or Collins straight sections, by

FIGURE 4

introducing wiggler magnets at their centers. Each wiggler consists of a multiple dipole which will produce alternating bends, "wiggles", in the electron beam, but no net deflection. The insertion must be matched to the arcs with magnetic lenses which can be designed to focus in both horizontal and vertical directions at the insertion center. Design of the entire ring lattice must produce particle orbits which are not markedly disturbed by the presence (or absence) of wigglers in the insertions. When properly designed such insertions can provide sources with very favorable optical properties for spectroscopy and diffraction.

Optical characteristics of electron storage rings have been examined in detail at Brookhaven in the course of conceptual design. Various types of wigglers were considered in this study, high and low field dipole multiplets, as well as the recently proposed wigglers with helically varying fields. The optical source quality obtainable from the arc bending magnets has also been studied. Calculations showed that a storage ring could be specially designed to provide extremely bright optical sources.

The electron beam has a distribution in transverse dimensions and angles given at any point in a specific ring lattice design by certain functions defined and discussed later in III.A. A real source subtends an arc and is extended in the direction of the optical axis as well as in the transverse dimensions. The source can be diagrammed in phase space by transforming radiation from each element along the arc to the arc center. The resultant phase space area then depends on several quantities: the transverse divergencies and sizes of the electron beam, the length of the source, and the opening angle of the cone around the electron orbit within which the radiation is emitted. Taking into account

these various factors, one establishes the following requirements for optimizing the optical features of the storage ring light sources:

1. Very small electron beam emittances (see III.A.1).
2. Low β points (see III.A.1).
3. Smallest possible bending radius, compatible with wave-length demands and power limitations.

In the present 2 GeV ring design, electron emittances have been minimized by the choice of a particular storage ring lattice which differs substantially from those used in electron rings built for high energy physics, and this design leads to an improvement by a factor of ~ 10 . Low β points are obtained by introduction of matched insertions. High field wigglers in those low β points further increase the source brightness in these locations because of the small bending radii associated with the high magnetic fields. A separate small radius 700-MeV ring provides VUV sources optically superior to those available in the arcs of the 2-GeV ring.

In summary, a prime objective in the Brookhaven design effort has been to provide very bright optical sources over the full spectral range - hard x-ray through the UV. A single ring designed to meet optimally the needs of x-ray users could also provide a few UV sources, at the expense of high brightness x-ray sources, by using low field wigglers in some straight sections. The optical needs of UV users, however, can be met in more nearly optimum fashion by the numerous sources which can be provided in a separate lower energy ring specially designed to serve their experiments.

C. User Requirements and Associated Design Criteria

1. Spectral Distributions

The availability of photon spectra peaked in different wavelength regions is a basic requirement for the community of synchrotron radiation users. The major reason for this is that soft radiation users need to have photon beams uncontaminated by the troublesome radiation at hard x-ray wavelengths, as discussed already in the last paragraph of II.A. There are also significant advantages to be gained by providing several spectral distributions, at spaced values of λ_c , so that various classes of experiments can be undertaken simultaneously under near optimum conditions.

Experiments in the hard x-ray region require spectral peaking in the vicinity of $1\text{\AA}$ with radiation at useful intensity levels extending down to some tenths of Angstrom units. This requirement will be met by the large ring in the Brookhaven design, when operated at 2 GeV with 40 kG wigglers. A clear need for spectra peaked below $1\text{\AA}$ has so far not been documented, but substantially shorter wavelengths could be achieved by using higher field wigglers and by some increase in ring energy. The 40 kG wigglers in the design are easily within the state-of-the-art, but it should be possible to develop 60 kG or even higher field wigglers if warranted by future user needs. The design margin in the facility (specifically in the rf system, quadrupoles, and bending magnets) will permit operation of the large ring at energies as high as about 2.4 GeV if need be.

Spectra suitable for the soft radiation users will be provided by the small ring in the Brookhaven design. When operated at its maximum energy of 0.7 GeV, for example, the small ring will provide a λ_c of $32\text{\AA}$ from its arc magnet ports and $19\text{\AA}$ from a 20 kG iron-copper

wiggle! In addition, a spectrum with λ_c at $5.7\text{\AA}$ will be available from the arc magnets of the large ring (when operated at 2 GeV).

2. Brightness

For experiments requiring high spatial resolution there is no substitute for high source brightness (photons/sec- $\text{\AA-mm}^2$ -steradian). While not necessary for some types of experiments, it is never a disadvantage. A basic aim at Brookhaven has been to provide photon sources of the highest practical brightness, and the design will yield brightness greater by at least an order of magnitude than that of any existing synchrotron or storage ring.

3. High Current Capability

Since photon flux is directly proportional to the circulating current in a storage ring, it is obviously advantageous to provide high current capability in a storage ring designed specifically for synchrotron radiation research. There are practical considerations, however, which limit maximum design currents. Among these is an adverse effect on the lifetime of the stored electron beam. Also, at some point there can be real problems in dissipating the high power densities of the synchrotron radiation itself as it impinges on optical elements and vacuum walls, as evident from the discussion in II.A. The Brookhaven rings are designed for operation with circulating currents approaching 1 ampere. This objective leads to an injection energy of about 700 MeV. While the ring booster designed for this purpose is a relatively simple device, it is somewhat more sophisticated than originally envisioned. In particular, the experiments planned with helical wigglers in the storage rings impose requirements not considered in the earlier preliminary design plans.

4. Time Structure

The time structure of the beam is expected to be very important for a variety of experiments. A storage ring can be loaded with as many electron bunches as the rotation time divided by the rf period, or as few as one. Important factors in radio frequency selection are cost, availability, and tube replacement costs of the rf generators. A pulse width of about 1 nanosecond can be obtained easily and should be adequate for much of the work under current discussion in the user community. Narrower widths are achievable, however, if user demands warrant the additional cost. This is left as a possible improvement for the future.

5. Operational Flexibility

A point emphasized in both internal discussions and consultations with members of the outside community has been that a new dedicated facility design should permit a range of operating conditions, so as to meet special experimental requirements as they might arise, and that reasonable allowances be made to cover possible future demands for expanded capability. The storage rings in the Brookhaven facility will have good performance characteristics over a range of energies and circulating currents. Various spectral distributions will therefore be tunable with energy and field to meet special experimental needs. An important advantage to be gained from such tunability, for example, is that the working wavelength for an experiment can be set on the rapidly falling slope of the flux curve for strong suppression of higher order contamination of a monochromatized photon beam. In addition, for experiments where polarization may be of critical importance, it will be advantageous to adjust λ_c to be near the working wavelength (see Figure 3).

Considerable advantage is gained in operational flexibility by providing two rings in the facility. Changes in operating conditions which may be desired by soft radiation users, for example, such as tuning λ_c by variations in E and B, can be made without disturbing conditions desired by hard radiation users.

There is much current discussion on the feasibility of helical wigglers. Should such a device prove to be practical in a storage ring, it can be accommodated in the framework of the Brookhaven design. Special attention has been given to helical wigglers in the course of conceptual design; the fields and orbits in helical wigglers have been analyzed and stability criteria have been applied to the orbits in a storage ring that includes such devices. The conclusion is that their use should be entirely possible. Extra length, therefore is being allowed in some straight sections and the injection booster has been re-designed to provide necessary damping characteristics.

Allowances for possible future needs for x rays below $1\text{ \AA}$ have already been mentioned in connection with the development of higher field wigglers. Continuing work in the latter area should be emphasized in the post-construction operational phase of the project even if no significant demand for shorter wavelengths emerges. Significant savings in rf power consumption could be realized by operating the large ring at lower energies.

6. Beam Lines

In first approximation the scope of a storage ring project follows in a natural way from the combinations of electron energy and magnetic field required to produce the radiation to be used in experiments. In detail, it is determined by the maximum number of developable beam lines and their individual requirements in optical characteristics.

The design group can then settle on a definite ring symmetry (which will determine the mean ring circumference), and an assessment can be made of the building space required for experimental and facility operations.

It is abundantly clear that the scientists who would make immediate use of a new dedicated facility, specially designed and operated to meet their needs, already number in the hundreds. The number of probable users of synchrotron radiation in the nation over the next decade can only be approximated, but it is certainly very large. The decision was made to provide for ultimate development of about 35 ports at the large ring, and about 16 at the small ring. Since a beam port can serve more than one experimental station (in most cases), the facility will be a sizeable operation when it reaches saturation. With this capacity, Brookhaven will be able to meet a major fraction of projected needs in the external community, in addition to serving the requirements of its internal ERDA programs.

There are important beam line apparatus components which must be thought of as integral parts of a synchrotron radiation facility. Their design in many cases must be meshed interactively with detailed design of the storage rings if the installation as a whole is to realize its full potential. Among such components are optical elements, certain complex photon detectors, some ultra high vacuum items, special spectrometers, and computer systems. Development will be needed for some of this equipment.

III. STORAGE RING SYSTEMS

A. General Design Considerations

As discussed in II.A., the wavelength of the peak of the radiation spectrum is inversely proportional to $E^2 B$, whereas the rf power, for a given circulating current, is proportional to $E^3 B$. Thus the wavelength of the spectrum peak can be shortened at less expense in rf power by increasing B rather than by raising E . Also only a small portion of the radiation from the electrons distributed around the necessary 2π of bend can be brought out for use. These considerations lead to the concept of short sectors of high magnetic field interspersed among sectors of relatively low field.

1. Particle Dynamics

The lattice of a synchrotron or storage ring is composed of a sequence of bending and focusing magnets. The functions of bending and focusing can be included in the same magnet or separate magnets can be used for bending and focusing. The latter "separated function" system is the one that is proposed for the rings in the Brookhaven facility. The radial and vertical motion through such a lattice is described in the classic paper of Courant and Snyder (Annals of Physics, 3, 1, 1958). An important function discussed by Courant and Snyder is the amplitude function β . If x is the radial displacement from the "equilibrium orbit", y is the vertical displacement and s represents distance along the orbit then

$$x(s) = A_x \beta_x^{1/2}(s) \sin\left(\int \frac{ds}{\beta_x} + \phi_x\right)$$

$$y(s) = A_y \beta_y^{1/2}(s) \sin\left(\int \frac{ds}{\beta_y} + \phi_y\right)$$

where A_x , A_y , ϕ_x and ϕ_y are determined by initial conditions.

The amplitude function β has the periodicity of the magnet lattice; its value can be determined by methods described by Courant and Snyder. Numerous computer programs are available for its numerical determination. When the distribution of the amplitudes and angles of the paths of all of the electrons in a beam are plotted in x, x' or y, y' phase space, the area of the distribution (elliptical in shape) is referred to as the "emittance" of the beam.

As can easily be seen from the expression for $x(s)$ and $y(s)$, the beam size will vary as $\beta_x^{1/2}$ and $\beta_y^{1/2}$ around the machine. Low β points are provided at a number of places in both the 700-MeV and 2-GeV rings to give maximum beam brightness.

One wavelength of the "betatron" oscillation is completed when

$$\int_{s_1}^{s_2} \frac{ds}{\beta} = 2\pi$$

Integration around the complete circumference will now yield the ν -value, the total number of betatron oscillation periods in one revolution. To avoid destructive resonance effects the machine should be designed to have a ν -value that is not close to an integer plus a small rational fraction.

An off-momentum particle will travel on a different equilibrium orbit, which, in general, is not parallel to the central orbit but will be one with wiggles correlated with the magnet lattice. The momentum dispersion function $X_p(s)$ is defined as

$$\Delta x(s) \approx X_p(s) \frac{\Delta p}{p_0}$$

where $\Delta x(s)$ is the local setover of the equilibrium orbit for a momentum deviation Δp from the central orbit corresponding to the momentum p_0 . Like the β -function, $X_p(s)$ has the periodicity of the magnet lattice.

As can easily be seen from the discussion of radiation power in II.A., the voltage per turn in kV necessary to make up for the radiation loss is given by

$$V_r = 88.5 E^4 / \rho \quad (E \text{ in GeV, } \rho \text{ in m}) .$$

During the acceleration cycle, as the electron beam energy is increased from the injection to the operating level, an additional voltage V_a (keV/turn) is required:

$$V_a = C \rho \dot{B}_0 \times 10^{-4} \quad (C \text{ and } \rho \text{ in m, } \dot{B}_0 \text{ in kgauss/sec}) .$$

Here C is the ring circumference, $\dot{B}_0$ the magnetic guide field rise rate.

The rf system supplying the voltage must operate at a frequency which is an integer (h , the harmonic number) times the revolution frequency of the electrons. Under these conditions, particles with momentum and phase (relative to the rf voltage) within a range around the stable phase angle (see below) and the central momentum, will undergo stable phase or synchrotron oscillations. The stable regions in longitudinal phase space are called rf "buckets". There will be h equally spaced buckets and the electron beam can occupy any number of them, depending on the filling mode. In other words, the electron beam will be in the form of 1 to h bunches. In order for the electron bunches to fit inside the rf buckets it is necessary that the applied gap voltage V be greater than V_r in the storage mode and greater than $V_r + V_a$ in accelerating mode. The stable angle ψ_0 is given by

$$\sin \psi_0 = \frac{V_r}{V} \text{ or } \sin \psi_0 = \frac{V_r + V_a}{V}$$

2. Radiation and Damping

The emitted radiation affects the longitudinal as well as the transverse motion. An electron whose energy deviates from the nominal one will during one revolution emit a slightly different amount of energy. The reason is not only the different particle energy, but also the fact that an off-momentum particle travels on a somewhat different path in the bending magnets where the radiation is emitted. This in turn leads to damping of the energy (or phase) oscillation amplitudes.

The radiation effects on the transverse oscillations are different in the vertical and horizontal planes. During the rf acceleration that takes place every revolution to make up for the radiation loss, there is a reduction in the otherwise invariant vertical oscillation constant A_y , introduced earlier, equivalent to damping of the vertical oscillation amplitude. The same is true for the motion in the radial plane, but here there is an additional effect causing antidamping rather than damping. When the electron emits radiation in the bending magnets, it moves to a different equilibrium orbit and there will be a change in the horizontal oscillation amplitude which is measured with respect to the instantaneous equilibrium orbit. This, together with the fact that the amount of radiated energy itself depends on the radial betatron amplitude, accounts for the antidamping. Fortunately, in a separate function machine with parallel edge bending magnets, the antidamping effect is zero and the entire radial damping effect obtained from the interaction of the electrons with the longitudinal rf accelerating field remains.

The effect of radiation on the synchrotron and radial betatron oscillations would be pure damping and hence negligibly small beam sizes if the energy loss would be a continuous process. Because the

radiation is emitted in discrete quanta, the damping effects in the longitudinal and radial phase planes are counteracted by excitation of random walk type oscillations resulting in finite longitudinal and horizontal beam sizes. Radiation excitation of vertical oscillations comes from the finite but very small forward angle with which the radiation is emitted, and can in general be neglected. Observed vertical emittance is the result of linear coupling to the horizontal motion; this coupling always exists in the ring because of imperfections.

The radial emittance is highly affected by the size of the momentum dispersion function in the bending magnets, with low X_p values leading to small emittances. In the present storage ring designs this fact has been utilized in a double sense:

(a) The regular bending magnets are incorporated in achromatic arcs in which the X_p function stays relatively small. Disregarding the wigglers, such a design results in a radial emittance about an order of magnitude smaller than that found in more conventional electron rings of comparable energy.

(b) The high field magnets (wigglers) are placed in the center of insertions in which the X_p function is matched to zero outside the wigglers and reaches a maximum as low as 0.005 m inside the wigglers. This prevents any significant increase in the radial emittance when the wigglers are turned on. In fact, in the present design, there is a slight decrease in the radial emittance coming from increased radial damping when the wigglers are on.

3. Space Charge and Instabilities

With a current of a significant fraction of an ampere, intensity-related effects are to be expected. The space charge defocusing effect coming from the electromagnetic field, produced directly or

indirectly by the beam, is negligible for highly relativistic particles such as 1 - 2 GeV electrons. A space charge effect that will reduce the lifetime of the beam is the so-called Touschek effect whereby transverse momentum is transferred into longitudinal momentum by Coulomb scattering between particles. The bunches will grow in longitudinal phase space and eventually spill outside the rf buckets. The Touschek lifetime is inversely proportional to the charge density of each bunch and consequently will be particularly short in the present design where the transverse beam dimensions are purposely minimized to achieve high beam brightness.

Transverse and longitudinal instabilities will be excited whenever there is a proper phase difference between the coherent oscillations of the beam bunches and the electromagnetic forces induced by such oscillations in the environment of the beam such as the vacuum chamber and the rf cavities. In electron rings a single bunch transverse instability of the headtail type is usually the most bothersome. Particles at the head of the tight bunches exert transverse forces on the particles at their tails through the wake fields due to finite resistivity of the vacuum chamber. However, as long as the chromaticity, defined as $dv/dp/p$ is positive and greater than a given value, all important oscillation modes will be stable. Hence it is necessary to install sufficiently strong sextupoles not only to cancel the existing natural negative chromaticity originating in the momentum dependent quadrupole focusing strength, but also to produce the necessary positive value of this parameter.

Other instabilities to be expected are caused by higher mode excitation in the rf cavities and various parts of the vacuum chamber which lead to heat losses as well. These can be suppressed by

installing damping loops in the rf cavities and by placing resistive absorbers in proper positions in the vacuum pipe, which itself will be designed to minimize rf excitation. Multibunch modes, in which the bunches "talk to each other" can also be eliminated by decoupling the bunch motion transversely by use of an rf quadrupole and longitudinally by installing a second rf system operating on a different harmonic number. Feedback can also be used to damp various instabilities. A low harmonic number is desirable to minimize most of these effects and an rf frequency of 53.5 MHz ($h = 24$) was chosen as a compromise to avoid excessively large rf cavities.

The high intensity effects described above have dictated the injection energy of 700 MeV in both storage rings. Extrapolation of experience gained at CEA and Doris with operation in a many bunch mode indicates that accumulation of a beam current of ~ 1 A is feasible at this energy.

B. The 2 GeV Ring

1. Lattice and Magnets

The lattice of the 2 GeV ring consists of six arcs matched to six insertions. The layout of one of the six identical sectors is shown in Figure 5, and its β and X_p functions are plotted in Figure 6. Each arc is made up of two achromatic bends separated by a quadrupole triplet. The horizontal dispersion function $X_p(s)$ stays below 0.5 m in this design, and the radial emittance is about an order of magnitude smaller than that found in more conventional electron rings of comparable energy and designed for colliding beam experiments. The beam is brought to a low- β focus ($\beta_x = 0.57$, $\beta_y = 0.35$ m) in the center of each insertion by triplets adjacent to the arcs. The insertion center is also the

location of the high-magnetic-field wiggler. It comprises three superconducting dipoles operating at fields corresponding to bends up to 3.7° , -7.4° and 3.7° . The fields will be in the neighborhood of 40 kilogauss. Such a dipole triplet restores the beam to the equilibrium orbit and has only a small effect on the radial emittance. It can be operated at fields bearing any desired ratio to the fields in the arcs (or even turned off). Although it is tempting to consider single high-field magnets, the fields in such single dipoles must be tracked with the fields in the other dipoles; the disadvantages outweigh the saving in rf power. (Less than half of the radiation from the wiggler triplet can be brought out of the ring and so much of the power is "wasted".) Two sets of sextupoles (12 and 24 respectively) (SF and SD in Figure 5) are required to compensate for the relatively large horizontal and vertical chromaticity. Sextupoles SF will be combined with the quadrupoles QF in the center of each achromatic bend while sextupoles SD will be incorporated in the adjacent dipoles in each half of these bends.

The bending magnets will be C-shaped and conventional in design. A cross section of a typical bending magnet is shown in Figure 7. The same magnet cross section will be used in the 2 GeV ring, in the 700 MeV ring and in the booster; thus magnet laminations produced by the same die can be used in the magnets of all rings.

The lattice described requires some of the radiation beams to penetrate the outer edge of the quadrupole structures; a slot will then be required, making the quadrupole structure analogous to a C-shaped dipole. Although some development work will be necessary, such magnets should be no real problem--judging from experience with narrow quadrupoles for beam transport which have been built at Brookhaven for several years.

FIGURE 5

FIGURE 6
AMPLITUDE AND MOMENTUM
DISPERSION FUNCTIONS, β AND x_p

BENDING MAGNET

FIGURE 7

Although the side sections of the iron yokes of these quadrupoles are omitted, they still provide good field patterns. The side coil can be split and the two magnet halves separated to create a slotted quadrupole; the field shape can be corrected by contouring the iron and by adding correction coils. Q1, Q2, Q4, Q5, and Q6 would take this form and would require pole tip fields no higher than 10 kilogauss. QF will be a 12-slot lens entirely surrounding the orbit. The SD sextupoles will be combined with the dipoles by contouring the iron and adding adjustable pole face windings.

The ring has the potential for ultimate development of 35 beam ports: 30 "simple" ports from the arcs and 5 specially designed wide angle ports from the transverse wigglers in the straight sections (one of the six straight sections is reserved for machine service functions). At 2 GeV the radiation spectra will have λ_c values of $5.7\text{\AA}$ for the arc ports and $1.2\text{\AA}$ for the wiggler ports (at a wiggler field of 40 kG). Most of the arc ports will be capable of serving more than one experimental station, with the degree of multiple use depending upon the angle requirements of the various classes of experiments. Each wiggler port will be a broad multiple port, so as to avoid the additional cooling requirements which would have to be met if more than one pipe were to be mounted close to the high power density wiggler sources. Again, depending on the class of experiment, each of these special ports could serve between 2 and 5 experimental stations. Thus, the ring will have a long range capacity for supporting quite a large research program.

Future use of helical wigglers is not excluded in the present design. Such wigglers would require free straight sections of the order of 5 m in length. A small dipole and an additional quadrupole would be required at each end of these straight sections to preserve the

equilibrium orbit of the machine and to accomplish matching of the helical wigglers to the ring. Alternate use of the longer straight sections for helical and ordinary wigglers is possible. However, if the low- β values of the shorter straight sections are to be reproduced, additional double focussing doublets or triplets will have to be introduced into the longer insertions.

2. RF System

The energy loss per turn of electron as it passes through the 8 kG bending magnets is 175 keV. In each 40 kG wiggler, the energy loss will be 26 keV. Accordingly, if six wigglers are included, the total loss per turn will be 330 keV (probably only five wigglers will be used because of machine service requirements in one straight section). With a beam current of one ampere, the total rf power, including cavity losses, will approach 500 kW. Peak voltages on each of two cavities can be as much as 500 kV.

To minimize operating costs, the power amplifiers which drive the rf accelerating cavities must operate at high efficiency and must have long lives. High power tubes are available with reasonable characteristics, yielding power of the order of 500 kW cw, up to about 100 MHz. At this frequency, tube efficiency is beginning to deteriorate and it seems wise to choose an operating frequency of about 50 MHz, corresponding to a harmonic number of 24.

The accelerating cavities will be simple cylindrical resonators with a small amount of capacity loading to reduce their overall size. Tuning will be necessary to compensate for beam loading and thermal effects; this will be accomplished by a mechanically variable capacitive tuner. The tuning range required will be of the order of 100 kHz.

3. Vacuum System

An ultravacuum will be required; it will be necessary to achieve pressures of 10^{-10} Torr without beam and 10^{-9} Torr with full beam. Experience with storage rings elsewhere indicates that satisfactory performance can be expected from an extruded aluminum chamber with an integral water cooling channel and with distributed titanium pumping to collect the large quantities of gas liberated when the wall is bombarded by radiation. Vacuum chamber cross sections suitable for inclusion in bending and quadrupole magnets are shown in Figures 8 and 9. The entire chamber will be surrounded by heaters for bakeout to temperatures of 150 - 175°C. Experience at SPEAR has shown that this process is needed rather infrequently but is essential occasionally.

Special care in design of the cooling system is required where side pipes are included for transmission of radiation to experimental apparatus. Also, where superconducting components are used, as in the high field wigglers, low temperature components must be protected from radiation. In general the angular deflections in high field wigglers will be small enough that the radiation will travel an appreciable distance before impinging on the wall. Special attention will have to be given to portions of the chamber on the inner circumference just downstream from the wigglers.

VACUUM CHAMBER
BENDING MAGNET

FIGURE 8

VACUUM CHAMBER
QUADRUPOLE MAGNET

FIGURE 9

4. Principal Parameters and Other Design Data

The ring of six superperiods would have the following parameters:

Length of one arc	14.7 m
Length of insertion	7.7 m
Circumference	134.5 m
$R = C/2\pi$	21.4 m
ρ (in BB)	8.17 m
R/ρ	2.62
	1.5 GeV 2.0 GeV
$B\rho$	50.1 66.8 kG-m
B	6.13 8.17 kG
Number of bending magnets	48
Weight of each	3000 lb
Power at 2 GeV	450 kW
Number of quadrupoles	66
Number of sextupoles	36
Number of wigglers	5 or 6
Max. wiggler bends (at 1.5 GeV)	3.7°, -7.4°, 3.7°
Max. wiggler field	40 kG

Dynamic Characteristics of the beam would be approximately:

ν_x	10.8
ν_y	6.9
$d\nu/(dp/p)$ uncorrected x	-31
uncorrected y	-28
ν_s	0.001
τ_x damping time at 1.5 GeV	9.5 msec
τ_y	9.5 msec
τ_s	4.7 msec

Dynamic Characteristics of the beam (cont'd.)

f_0 rotation frequency	2.23 MHz
f radio frequency (depending on user requirements, this may be doubled)	53.5 MHz
h harmonic number	24 (48)

Power to beam in w/mA or kw/A:

	<u>Ring</u>	<u>Transverse Wigglers</u>	<u>Total</u>
1.5 GeV	55	88	143
2.0 GeV	173	155	328
No. of cavities			2
Peak voltage, each			350 kv
Touschek life (small bunch lengthening)			
@ 1A, 1.5 GeV			1 hr.

C. The 700 MeV Ring

A small 700 MeV ring, intended for users interested in the UV region of synchrotron radiation, has also been designed. Its general layout is shown in Figure 10. Similar to the 2 GeV ring, its lattice configuration is aimed at minimizing the electron beam emittance. The ring consists of four achromatic arcs connected by straight sections. The straight sections, which are designed as matched insertions, will be used for wigglers of either the conventional or the helical type. They will also be used for injection and rf accelerators. The maximum field in the bending magnets is ~ 12 kG. The horizontally focussing quads QF between the two dipoles in each arc make the horizontal dispersion function zero outside arcs. This function reaches a maximum of ~ 1 m in quadrupoles QF. The triplets adjacent to the arcs focus the beam at the center of the straight section. Depending on the settings of the triplets two sets of β -values (low or high) can be obtained at the insertion centers.

700 MeV RING

FIGURE 10

For conventional wigglers low β values are desirable to achieve high beam brightness, while the high β values are necessary for an optical match of the helical wiggler to the ring. High β values are also required for injection to avoid an excessively thin septum in the injection magnet. Sextupoles SF and SD will control the chromaticity of the ring. β and X_p functions are shown in Figure 11. A summary of the basic machine parameters is given in the Table at the end of this section.

The energy loss per turn in the ring (not including wigglers) is 11 KeV at 700 MeV. It will be supplied by a 50 MHz rf cavity with a gap voltage of 100 KV. Although an adequate quantum lifetime can be achieved with much lower voltage levels, a gap voltage of 100 kV will give a sufficiently large rf bucket to ensure an acceptable Touschek lifetime. With a circulating beam current of 1A, taking into account bunch lengthening, a beam life of ~ 2 hours can be expected. The total rf power, including cavity losses, will be ~ 20 kW.

Principle Parameters and Other Design Data

The ring of four superperiods would have the following parameters:

Length of one arc	4.50 m
Length of insertion	6.50 m
Circumference	44.0 m
$R = C/2\pi$	7.0 m
ρ (in BB)	1.90 m
R/ρ	3.67
	0.7 GeV
$B\rho$	23.34 kG-m
B	12.3 kG
Number of bending magnets	8
Weight of each	4000 lbs.

Parameters for the ring of four superperiods (cont'd.)

Power at 0.7 GeV	220 kW
Number of quadrupoles	28
Number of sextupoles	12
Number of wigglers	2

Dynamic characteristics of the beam would be approximately:

ν_x	4.1*
ν_y	3.2*
$d_v/(dp/p)$ uncorrected x	-14
uncorrected y	-18
ν_s	0.002
τ_x damping time at 0.7 GeV	20 msec
τ_y	18 msec
τ_s	9 msec
f_o rotation frequency	6.8 MHz
f radio frequency (depending on user requirements, this may be doubled)	53.5 MHz
h harmonic number	8
Power to beam in w/MA or kw/A at 0.7 Gev	11
No. of cavities	1
Peak cavity voltage	100 kV
Touschek life (small bunch lengthening) @ 1A, 0.7 GeV	2 hr.

* Assumes two low β and two high β insertions.

D. Injection System

The injection system will consist of a 50 MeV linac and a 700 MeV booster synchrotron. This combination is required to achieve circulating currents of 1A in both the 700 MeV and the 2 GeV rings. The radial

FIGURE 11. β AND x_p FUNCTIONS, 700 MEV RING

betatron motion in the booster has to be damped if helical wigglers are to be used in conjunction with the storage rings. This is because the vacuum chamber aperture may be constricted to as little as about 1 cm at the location of the wigglers.

A simple separate function booster has been designed consisting of two 180° arcs, each containing 3 FODO cells. The lattice is shown in Figure 12. Straight sections, 1.5 m in length, connect the two arcs. These are inserted between the two halves of a cell defocussing quadrupole. In this way, the X_p function stays matched while the periodic variation of the β -function in the cell will be somewhat perturbed. The maximum values of β_x and β_y are 11.4 and 7.5 m. The magnetic field in the dipoles is 8.15 kG at 700 MeV. One of the straight sections will be used for injection and for rf acceleration, the other for ejection.

A ~ 50 MHz rf system results in a harmonic number of 6. Injection and ejection kicker demands can be greatly reduced by chopping the linac beam and filling only one or two out of the six rf buckets. With a 20 mA linac current and a 0.75 sec acceleration cycle (0.25 sec flat top) it will not take more than 9 and 3 minutes to fill the 2 GeV and 700 MeV ring, respectively. The energy loss per turn in the synchrotron booster is 7.5 kV at 700 MeV.

The basic booster parameters are as follows:

Energy	700 MeV
Circumference	34.2 m
Revolution Time	0.11 μ sec
Bending Radius	2.86 m
v_x	1.72
v_y	1.59
Momentum Compaction Factor	0.45
Horizontal Damping Time*	0.02 sec

The basic booster parameters (cont'd.)

Vertical Damping Time	0.02 sec
Longitudinal Damping Time *	
Horizontal rms Emittance	$\sim 3 \times 10^{-7} \pi$ m-rad
Harmonic Number	6

* Assumes parallel edge bending magnets.

FIGURE 12. BOOSTER LATTICE

IV. BUILDINGS AND UTILITIES

The specialized properties of the synchrotron light source and of its research program set the requirements of the buildings and services.

The most significant of these are as follows:

- a. A very stable base for the storage rings and the optical beam lines. This is probably the single most critical technical requirement of the structure.
- b. An air temperature of about 75°F which must be maintained with small but reasonable variation to match the mean cooling water temperature.
- c. A controlled humidity level so that the dew point will always be well below the cooling water inlet temperature.
- d. Components are of small unit weight. This affects the design of the base and material handling methods.
- e. The electrical power demand is relatively small.
- f. Control of cooling water temperature is to be maintained for thermal stability of the storage rings.
- g. Beam lines and research apparatus are of small size and weight with low power and cooling water demands.
- h. Vibration must be minimized by separating rotating machinery from the ring building.
- i. Attached auxiliary space is to be provided for control rooms, laboratories and offices.

These requirements can be well satisfied by a modular, prefabricated or "pre-engineered" industrial type structure erected on a thick reinforced concrete slab. The area inside the storage rings will hold the injector and auxiliary, mostly electrical, equipment. Corners of the rectangular structure will be utilized for some long beam lines, staging

areas for experiments, and storage of equipment not in service. Ductwork and primary services will be suspended overhead from the beams and purlins. Since ring parts and shield blocks will weigh no more than 4000 lb. each, they can be handled by standard floor-running equipment. A wing ~ 6000 sf will house the control rooms, laboratories and some offices. Additional laboratory and office space will be provided in the existing Accelerator, Biology, Chemistry and Physics Departments buildings. An industrial type structure on a separate foundation will house all rotating service machinery.

A. Foundation Base

The overburden will be scraped away to compacted sand. A thick reinforced concrete slab will be placed in a continuous pour without joints or trenches. The concrete membrane will smooth small irregularities and spread the loads: Long span stability (greater than 10 to 20 ft.) is provided by the sand. The glacially compacted sand underlying Brookhaven National Laboratory has proved to be a stable and predictable base. If loads are kept below a few thousand psf, preferably below 3000 psf, the sand behaves like an elastic medium with some hysteresis. There are no indications of heaving or quasi-liquid behavior. The soil mechanics properties have been measured to high accuracy at the AGS which is nearby the proposed site. A check will be made to verify that soil conditions are similar.

Loading over an appreciable area gives a prompt settlement of 80 mil per 1000 psf with a rebound of about 2/3 that when the load is removed and a reloading curve parallel to the rebound curve. Most of the loads imposed by this facility will produce deflections of a few mils. The 2 GeV ring shielding will weigh about 8000 lb. per circumferential foot. If a sector of this shielding is removed, the ring will

rebound 10 to 25 mils (depending on length of the sector) and will recover to within 2 or 3 mils when the shielding is replaced for operation. The only alignment problem anticipated could come from a heavy snow load. Once every few years the snow load on the roof will approach or exceed 10 psf. Forces transmitted through the columns could then disturb the ring alignment and interfere with operation until the snow is melted or removed. Removal of the load will restore alignment well within the range of the correcting coils. Since such a heavy storm would disrupt operation anyway, there is no justification for incurring the heavy expense of incorporating a long span roof structure to avoid this problem.

Years of experience with the AGS indicate that realignment of the rings will be required only at long intervals. Heavy loads in this facility will seldom be shifted. After a year or two, from pour, the anneal temperature cycling beneath the slab will be very small. Provision for alignment will be made by casting pipes in the internal shield wall for access by alignment tools. These small rings can then be aligned to high precision with radius tapes, templates and optical levels.

B. Structure

The most economical structure is a pre-engineered shell with modules about 25 by 50 ft. The locations of support columns have been taken into account in the machine design and do not offer serious obstructions. Panels for sidewalls and roofs will be well insulated and a thick impervious mat will insulate the slab edge from the grade beam. These structures will be ordered complete with conventional HVAC, sprinklers, lighting, partitions, doors, toilets, etc. An eave height of 20 ft. will give about 17.5 ft. net clearance under the eave and about 25 ft. clearance

at the ridge. The office and laboratory wing will be attached to the sides of the ring housing, and will be furnished with interior partitions and acoustical hung ceilings. The accelerator building will have a sheet metal sidewall liner but the roof steel will be left exposed so that services can be suspended from it.

A mechanical equipment building about 4000 sf will be erected on a separate foundation to minimize vibration in the main slab. This building will contain the chillers, pumps, heat exchangers and compressors. Adjacent to it will be located the substations and evaporative coolers.

C. Power

The peak demand is estimated as follows:

Magnet systems	1700 kw
Rf systems	1100
Small ring systems	100
Research apparatus	200
Mechanical services and building	1000
	<hr/>
Peak demand	4100 kw

The incoming feeder will be 13.8 kv, 3-phase, and 10 Mva. Major rf power supplies using about 1000 kw will be supplied at 13.8 kv. The other loads will be supplied by two 13.8 kv/480 v, 3-phase 2500 kva unit substations packaged with load disconnect and secondary breakers. Four heavy bus duct feeders will route to three distribution centers in the rings and one in the mechanical equipment building. Each distribution center will contain a 100 kva 480/120-208 v transformer for low power apparatus. An additional 120/208 v transformer will be located in the laboratory wing for power and lighting. Power for experiments will be distributed in bus duct hung on the outer periphery of the ring and shielding. Refer to Figure 13 for 480 v feeder schematic.

D. Cooling

Evaporative coolers will supply water through a closed circuit to the high power rf system, the chiller condensers and the HVAC condensers. Total peak demand, divided among four units, will be about 9 million Btu/hr. The dew point during much of summer is too high for cooling the magnet systems and vacuum chambers. For this reason about 600 T of chillers will be installed to provide a mean temperature of 75°F and rise of 15-18°F. When the dew point is sufficiently low, control valves will divert load from the chillers to the evaporative coolers. Demineralizers will be provided in the closed water circuits to maintain a high degree of water purity. Major supply and return piping will be routed to a few distribution points from which prefabricated manifolds will feed the multiple cooling connections. (See Figure 13.)

E. Material Handling

Unit parts of the rings and shielding will be kept to about 4000 lb. maximum. These parts can then be handled by a telescoping hydraulic boom crane operating on the slab. A fork lift will be captive inside the 2 GeV ring for materials transfer to the boom crane. Sectors will be kept clear of long beam lines to provide access, and one or two overhead monorails will be mounted as auxiliaries. Elimination of overhead crane coverage permits free use of vertical space for service risers and elimination of trenches in the slab. This not only reduces cost but also improves stability. Extensive material handling will not often be required during operation of this facility. The beam lines and experimental equipment are light in weight and will be installed with normal laboratory handling equipment.

OFFICE AND
LABORATORY WING

Computer
Room Control
Room

FIGURE 13

F. Site

The site envisioned at present is south of the Instrumentation Division building and has close access to the various services and utilities. If future detailed examination of soil and drainage, or other considerations, should so warrant, another site can be selected from the several alternate locations also considered at this stage.

V. OTHER INFORMATION DEVELOPED IN CONCEPTUAL DESIGN

A. Shielding

It is important that experimenters have good access to their equipment during normal operation of the stored beam. There will be occasions where requirements on having a first optical element close to the point of the light source, and perhaps even in the main vacuum of the machine imply low accessibility for the experimenter. The shielding indicated below further increases the distance of closest approach of the first highly accessible element on an experimental beam line. The shielding is, of course, essential to allowing general access to the experimental floor and radiation levels will be monitored during machine operation. There are a variety of sources of radiation requiring shielding. For example, during a run some of the electrons are spilled from the beam and collide with vacuum chamber walls and adjacent hardware. Much of the attendant radiation, except for photoneutrons, will be satisfactorily contained by a 6-8 cm thick belt of lead external to the vacuum chamber of the 2 GeV ring. There will be photoneutrons with energies ranging up to roughly 60% of the electron beam energy, however, and these require concrete shielding. Aspects of this problem are considered in the three paragraphs which follow.

1. Catastrophic Spills

While there will be a well-shielded beam dump it is conceivable that the beam might be accidentally dumped somewhere else in the vacuum system. The consequences of dumping a 1 amp 2 GeV beam can be estimated by scaling the calculations¹ of Alsmiller and coworkers for the photoproduction of neutrons and for their shielding. Assuming two feet of concrete

1. T. A. Gabriel and R. G. Alsmiller, Jr. ORNL-4443 (unpublished Oak Ridge National Laboratory 1969 (and R. G. Alsmiller, Jr. and J. Barish, Particle Accelerators 5, 155 (1973)).

shielding, as allowed for at present in construction plans, the maximum dosage is associated with standing just outside the shielding at the point where the beam is dumped. This dosage is found to be less than 100 mRem. Its low value is largely a consequence of the fact that only a few, i.e. $\sim 3 \times 10^{12}$, electrons are stored in a 1 amp beam in the 2 GeV machine.

2. Continuous Beam Spill

Electrons are lost from orbit in the course of a normal beam run. Some will be picked up by a beam scraper and a substantial fraction of the initial beam will go into the beam dump at the end of the run, but some will be lost around the ring during the course of the run. Assuming a month of twenty 9-10 hour shifts and that half the electrons present after loading are lost by spillage round the 2 GeV ring, the monthly dosage immediately outside the concrete shielding will be less than half that associated with a catastrophic spill. Inasmuch as a worker will normally not spend his entire month leaning on the machine shielding, but will on the average be further away, the normal monthly dosage from continuous spillage will be very much smaller. We estimate a typical dosage from this source to be of the order of a mRem per month on the 2 GeV machine.

3. Spillage on the 0.7 GeV Ring

Radiation levels due to spillage will be an order of magnitude lower on the 0.7 GeV ring. First, there are fewer electrons stored in the ring: granted a ring circumference which is 1/3 as great, 1/3 as many electrons are stored in the ring at some given machine current. Secondly, the photoneutron dosage associated with stopping an electron, scales roughly with the electron's energy. This provides another factor of 1/3 on going from the 2 GeV to the 0.7 GeV ring.

4. Beam Loading

Radiation levels at the time of injecting a beam into a ring and bringing it to full energy depend in detail on loading procedures. In general, the radiation levels are significantly higher during this time and it has been the practice at some synchrotron radiation facilities to clear the experimental floor surrounding the ring of personnel during loading (loading time is the order of minutes on the proposed facility). This is inconvenient and, given the shielding provided the two rings, efforts will be made to develop loading procedures which will let personnel stay on the experimental floor. Requirements on the final beam and hence on its loading may not allow this, however.

5. Linac and Booster Synchrotron

The 50 MeV linac will require some concrete shielding, of the order of two foot thickness, downstream and in the beam transport region. The 700 MeV synchrotron will have a 50 milliamp current and 3/4 sec cycling period. It will require concrete shielding round the injector and in local regions where losses are found to be high. Significant shielding of personnel comes from the fact that these two devices will be located inside the 2 GeV ring.

6. Beam Lines

The photon beam lines penetrate the main shielding of the rings and this introduces several potential radiation hazards. Electrons straying outside the main orbit may hit the vacuum walls upstream of the beam port at points in view of the port where neither the lead nor the concrete shielding intervene. The area of wall in view can be greatly reduced by detailed shaping of the vacuum chamber upstream and by the introduction of collimators in the beam line. Electrons hitting the vacuum wall immediately downstream of the port can also produce radiation which, after going through a thin layer of shielding, also enters

the beam line. Collimators also reduce this effect. Permanent magnets, placed on the beam line, can be used to sweep out any charged particle.

Procedures will be established to keep personnel out of the photon beam lines at all times both against exposure to the primary synchrotron radiation beams and to any other small amounts of radiation coming down the pipes. The effects of scattering these radiations off axis either due to residual gas or to optical elements in the beam lines will be monitored and local shielding employed when and if it proves necessary.

B. Wigglers

Design of the bending and focussing lattice of the circular portion of a storage ring has limitations imposed by the requirements of stability and small emittance. Momentum dispersion in the bending magnets increases the x dimension of the electron beam; double focussing in x and y is difficult to achieve; and the ratio E/B (that is, the radius) is fixed. In an insertion region between the arcs the momentum dispersion can be virtually zero; and strong magnetic lenses can give a double focus of the beam. A short triple dipole magnet (transverse wiggler) placed in the insertion will thus produce radiation from a very small source with little adverse effect on the electron beam elsewhere round the ring. There is also much interest in possible application of the helical wiggler. A helical, small bore magnet can produce circularly polarized radiation on axis with very high flux in a narrow spectral range. This radiation can be advantageous for several classes of experiments. Preliminary studies indicate that the helical wiggler can probably be used on a storage ring.

1. Transverse Wiggler

Fields of 40-60 kilogauss can readily be generated in superconducting windings. Using a set of split solenoids, the electron orbit undergoes a zero net deflection upon passing through the wiggler. The solenoid coils are located above and below the orbit, separated by a sufficient distance to allow passage of the beam and transmission of the emitted radiation. The critical wavelength, λ_c , of the spectrum from a 2-GeV electron in a field of 40 kilogauss is about $1.2\text{\AA}$. If the field is increased to 60 kilogauss the critical wavelength will be reduced to about $0.8\text{\AA}$. Located at a focal point of a low emittance storage ring, this wiggler would give the smallest and brightest x-ray source available with present technology.

Wigglers, if need be, can also produce spectra at longer wavelengths in high energy rings. In the 2-GeV ring, for example, where the radiation from the orbits in the arc bending magnets has a λ_c of about $6\text{\AA}$, spectra peaking at much longer wavelengths could be obtained by running wigglers at low fields. If, for example, a spectrum with $\lambda_c = 40\text{\AA}$ is desired, it could be obtained by running a wiggler with fields of about 1.2 kilogauss. Such wigglers would require much longer arc bends than in the high field case, and one could not simply run a 40 kG unit down to such a low field. A different design would be required.

The superconducting coils of a high field wiggler will each require about 3 million ampere turns. In the coils themselves there will be no losses so the only demands on the cooling system will follow from lead losses and from direct thermal conduction through the wall of the Dewar system in which the coils are enclosed. It is estimated that about 20 liters of helium per hour will be evaporated. The

losses can be reduced by short circuiting the coils and operating them in the persistent superconducting mode. Dahl and Sampson (BNL Report 20079) have done preliminary studies of such a device and their calculated field distribution is plotted in Figure 14. The coils were designed to be wound from the wide braided conductor utilized generally in the BNL superconducting accelerator magnet program. The calculations assumed an air core design, although the final device will most likely incorporate an iron yoke, which can further enhance the field strength, tailor the field shape somewhat, and help support the coils against the considerable magnetic forces. With a 35 kG deflecting field on the magnet axis, for example, the peak field is 49.6 kG, and occurs on the inner surface of the main winding.

Such transverse wigglers will be devised to work within specific ranges of field strengths. The storage rings can be operated with such a device either turned on or off. The optical properties (beam position and source size) of the electron orbit at other radiation ports on the ring will not be significantly affected when such a wiggler is turned on.

2. Helical Wigglers

The helical wiggler is a variant of the "free electron laser" evolved at Stanford and recently tested using a beam from one of the Stanford electron linacs. In this device a transverse magnetic field is generated whose direction rotates continuously with distance along the axis - the axis being coincident with the axis of the electron beam.

Such a field can be generated by excitation of an open helical winding. In the open spaces between the turns of one winding, a second is wound and is excited with current flowing in the direction opposite to the current in the original winding. This current

FIGURE 14. CALCULATED WIGGLER FIELD DISTRIBUTION. DAHL-SAMPSON MODEL

combination produces a field pattern with a zero axial component on the axis and with a transverse component which rotates with the same period as the pitch of either helix. The transverse field varies slowly near the axis, then increases rapidly as the winding is approached; this variation places severe limits on achievable transverse fields and on the useful thickness of the winding. For example, to obtain transverse fields of 6 kilogauss in a helix of pitch 2 cm, the maximum inner diameter of the wiggler will be about 1 cm and current densities of the order of $50,000 \text{ amperes/cm}^2$ will be required. Evidently only superconducting windings will be usable.

The electron orbits in the field patterns for such a device were traced in a number of computer runs and were found to agree with orbits derived from an approximate form of the equations of motion. The primary motion is helical with an orbit radius that is a small fraction of a millimeter and a pitch which is the same as that of the transverse field. The instantaneous axis of the helix is tangent to a sinusoidal "betatron oscillation" which lies in a plane through the axis of the wiggler. For a range of possible wiggler parameters the frequency of this oscillation is two to four orders of magnitude slower than that of the helical motion. Its phase and amplitude are determined by initial conditions. By a suitable (non-zero) choice of initial transverse velocities the amplitude of the betatron oscillation can be reduced to negligible values; with this correction all electrons, including those off axis will pursue helical paths whose axes are parallel to the wiggler axis and whose radii are almost identical.

The spectrum emitted by this wiggler will be peaked at a wavelength which is approximately the pitch of the helix divided by v^2 where v is the ratio of the electron energy to its rest energy. Thus,

for a 2-GeV electron in a helix of 2-cm pitch, the spectrum will be peaked at about $12\text{\AA}$. The fractional bandwidth of the spectrum will be approximately $1/N$ where N is the number of turns in the helical winding.

The primary helical motion of the electron will have such a small diameter that its pitch angle will be of the same order as the angular width of the radiation cone emitted by the electron. Thus the radiation pattern emitted through the end of the wiggler will be a cone whose outer edge makes an angle with the wiggler axis which is the sum of radiation cone angle and the pitch angle of the electron's helical motion.

The general behavior of electrons in the 20 MeV range in a helical wiggler has been checked at Stanford. Whether or not such a wiggler can be included in a storage ring has been studied at Brookhaven where it has been concluded that, with proper attention to initial and final conditions at the wiggler, stable orbits can probably be maintained. By coupling x and y motions of the orbit, the presence of such a wiggler adversely affects the optical properties of the electron beam elsewhere in the ring. However, such devices offer the possibility of circularly polarized light which is of some orders of magnitude higher flux, in the peak of its spectrum, than that available from conventional synchrotron radiation.

The properties of helical wigglers and the behavior of electrons therein have been described recently in companion papers "A Short Period Helical Wiggler as an Improved Source of Synchrotron Radiation", by B. M. Kincaid of the Bell Laboratories, and "Orbits and Fields in the Helical Wiggler", by J. P. Blewett and R. Chasman of BNL. These papers have been submitted for publication in the Journal of Applied Physics.

C. Experimental Equipment

Apparatus such as monochromators, detectors, data acquisition systems, and vacuum equipment for use in the photon beam lines emerging from the storage rings will require substantial expenditures; a fully instrumented experimental station costs several hundred thousand dollars. It is essential that a substantial investment be made for experimental equipment during the construction period. Some components of the beam line equipment will, in effect, be elements of the storage ring vacuum systems. Also, since the rings are to provide light sources of superior quality, it is important for equipment design work to proceed on a parallel and interactive basis with the detailed design of the storage rings. Finished prototypes of experimental stations will be required for performance testing and diagnostic work at initial start-up and during operational run-in. Finally, this period can be utilized for solving equipment development problems and for strengthening certain of the instrumentation capabilities at the Laboratory needed for support of the facility.

The equipment funds included directly in the project construction budget will cover the high priority items needed to meet the objectives outlined above, and will provide a modest base of usable equipment when the facility becomes available. A substantial accompanying research and development effort will be required on some special items, however, and a sizeable capital investment must also be anticipated to activate additional stations and to meet the needs of an expanding research program. These R&D and capital requirements are noted appropriately in Section VI.

In general, equipment for research with synchrotron radiation can be classified according to the spectral ranges used in experiments. This determines the type of monochromator (normal or grazing incidence, crystal),

local shielding requirements, vacuum equipment (including ring vacuum protection), interaction with ring geometry (small ring, large ring, arc source or straight section). Even within a particular spectral region, however, there can be substantial variations in equipment requirements for different types of experiments. In the hard x-ray region, for example, quite different types of spectrometers are needed for extended x-ray absorption fine structure (EXAFS), crystal diffraction, and small angle scattering. One must also take into account the rapid changes in instrumentation for synchrotron radiation research. Equipment is becoming increasingly sophisticated, as is always the case when a new tool comes into use. Many changes can be expected over the years before the Brookhaven facility becomes operational. These advances will, of course, be exploited in experimental station designs.

In substantial measure, however, basic requirements can be anticipated. New and improved monochromators, for example, will certainly be developed, but the problems associated with providing maximum accessibility, stable and conveniently adjustable mounts, cooling (when necessary), etc. are subject to definition. Some development directions on the monochromators themselves can be foreseen, such as layered x-ray monochromators, for example. Faster energy sensitive detectors than those currently available are needed both for spectroscopy and, in some cases, simply for sorting out extraneous higher order wavelengths impinging on a detector. Similarly, one would like higher resolution x-ray video detectors: a resolution of 1 μm , as compared with the 20 μm currently available, would be useful for, say, x-ray topography. Position sensitive area detectors will be very important for several types of x-ray diffraction experiments. Studies in the VUV on surfaces will require auxiliary instrumentation, such as Auger and LEED equipment for full characterization

of a surface under study, mounted as integral components of an experimental station. A flexible computer system will be required for on-line experimental control and data acquisition. The Brookhaven Computer Systems Group in the Instrumentation Division has considerable experience in this area and a study for such a system for the synchrotron light source has already been completed (available as an Informal Report, BNL 21109, April 1976).

Eight fully equipped experimental stations are proposed, divided between x-ray and UV usage. These would be installed in the insertions and in bending magnet regions. Although the exact choice of the particular classes of experiment these stations will serve and of details of instrumentation will be made later, as the time of utilization approaches, the nature of some parts of the installations can be anticipated. There will probably be at least one station for angular dependent photoemission spectroscopy, a diffraction station employing the area detector and, of course, capacity for doing x-ray absorption spectroscopy; these, of course, will have computer capability. In addition to the eight complete installations, several beam lines will be partially instrumented, including monochromators, so as to expedite their activation early in facility operations. In a number of instances it will be desirable to have the first optical element, a mirror, crystal or grating, as close as possible to the light source. In some cases this will necessitate placing the element inside the main machine vacuum. This will affect the vacuum and shielding design of the rings. The design of the vacuum chamber in the vicinity of a beam port can be complicated by the requirements of getting the light out while minimizing any perturbations on the electron orbits and any stray radiation going down the photon line. This is but one of the areas where design of the rings and design of the experimental lines interact strongly.

It is important to emphasize that the full instrumentation effort (project, R&D, and capital) is not intended simply to provide for limited initial testing and experimentation but is expected to furnish the base of laboratory experimental capability on which the national program of the facility will rely.

VI. COST ESTIMATES AND PROJECT SCHEDULES

A. Construction Schedule

The design, procurement, and construction schedule for this project is shown on the following page.

Construction of the facility covers a period of three and a half years, including a six-month run-in period before the machine is ready to support an experimental program. To meet this schedule some preliminary and accompanying support work is required (see Section VI-D). If authorization is granted for construction at the beginning of FY 1978, the experimental program can begin in April 1981.

The preparatory work necessary is to make possible placing orders of critical path and long delivery items immediately upon authorization. This includes buildings, magnets, vacuum components and other major construction items.

B. Manpower

The project manpower requirements are shown in Table VI-1. The estimate is given by fiscal year and is broken down into two broad categories; professionals (scientists and engineers), and non-professionals (technicians, draftsmen, and others). The totals estimated are 132 man-years (62 professional and 70 non-professional) for ED & I and 77 man-years (non-professional) for assembly and machine shop manpower associated with the storage rings and associated equipment. This estimate does not cover research and development activities, which are discussed in Section VI-D.

C. Cost Estimate

Details of the cost estimate are presented in summary Table VI-2 and in the detailed breakdown of Table VI-3. The estimate is based on current costs for labor and materials, with contingency and escalation

LR - Large Ring
SR - Small Ring

amounts added as described below. The schedule of fiscal year obligations is shown in Table VI-4. An analysis of escalation and contingency amounts and the details of the total obligation flow are given in Table VI-5.

1. Site, Buildings, and Utilities

The building estimate is based on the "pre-engineered" type structure described in Section IV. The cost estimates are based on quotes from several fabricators; utility estimates are based on Brookhaven experience. Appendix A contains the building and utilities engineering estimate work sheets.

2. Storage Rings and Associated Equipment

The estimates for components of the storage ring facility and its auxiliaries are based on Brookhaven's extensive experience with similar components during the construction of two major accelerators. Where possible, estimates have been obtained from vendors.

3. Engineering, Design, and Inspection

This estimate is based on the manpower schedule shown in Table VI-1 and on salary levels similar to those currently in use in Brookhaven's Accelerator Department, plus the Laboratory's current benefits costs. The total amounts to approximately 28% of construction costs.

4. Contingencies

Based on BNL's experience and comparisons with other construction projects, contingencies are estimated at approximately:

15% on buildings and utilities

23% on storage rings and associated equipment

15% on ED & I

5. Escalation

The escalation estimates are based on the assumption that "in-house" manpower costs will escalate at a 6% rate per year and that building

and apparatus costs will rise at 8% per year. The escalation rates are applied to the anticipated obligation flow during each year, with the assumption that the project will be funded in FY 1978. Construction cost obligations are expected to be complete by the end of the first quarter of FY 1980. Details of the escalation calculations are shown in Table VI-5.

D. Research and Development

This facility will serve a broad range of interest in various ERDA programs, as well as an extensive outside user community from university and industrial laboratories. During the conceptual design phase, therefore, the project has profited greatly from efforts and technical data from various sources having long-term interests in the facility. Continuing research and development work is expected to require operating expenditures as follows:

(in thousands)

FY 1977	\$ 500
FY 1978	500
FY 1979	500
FY 1980	400
FY 1981	400

The broad purpose of this effort initially will be to follow up the work accomplished in conceptual design with more definitive examination of key components of the project so that detailed design and facility construction can proceed as efficiently as possible. This supporting activity will be of critical importance, especially in FY 1977 and FY 1978, for meeting the project schedule. Work in the later stage will turn more to a program of development of new and specialized experimental apparatus for use on the beam lines.

E. Facility Operation

Estimated annual costs associated with the operation of the proposed facility and the BNL in-house research programs are summarized below. Amounts, shown in FY 1976 dollars, would cover the first year of operations with 10 eight-hour shifts per week scheduled for research during this initial period, plus an allowance for maintenance, machine physics, etc. It is planned to activate eight beam lines during this first operating year; a staged development for several subsequent years will involve activation of additional beam lines with an accompanying expansion of research programs. Over a five-year period, the budget is expected to rise by about 35% (in unescalated dollars), with a major portion of the increase identified with the research budget component. Facility operating costs encompass those expenses for experimental area operations, equipment and machine development, and technical support for users, as well as costs associated directly with operation and maintenance of the machine itself. Capital costs are for equipment for both BNL and outside users. In order to have equipment ready for experiments at the eight beam lines, this level of equipment funding will be required beginning two years prior to operation of the facility.

The cost estimate is given in FY 1976 dollars because of the uncertainties of inflation factors, especially for electric power rates and prices of materials and supplies.

	<u>Cost in Thousands</u>
Facility Operations	\$ 2,100
Direct Manpower, including benefits (18 Professional, 24 Non-professional)	\$ 920
Materials, supplies, & supporting services	305
Electric Power (15,000 MW hrs. @ \$26/MW hr.)	390
General and Administrative	485

	<u>Cost in Thousands</u>
Research Program	\$ 1,230
Direct Manpower, including benefits (17 Professional, 8 Non-professional)	605
Materials, supplies, & supporting services	290
General and Administrative	335
	<hr/>
Total Operating Costs	\$ 3,330
Capital Equipment	800

Research programs at the facility will encompass several scientific disciplines. It is anticipated at this time that BNL utilization of the facility will include programs in Materials Sciences, Molecular Sciences, and Biomedical and Environmental Research in approximate percentages of 55, 30 and 15 respectively.

TABLE VI-1

PERSONNEL ESTIMATE

(Man-Years)

	<u>Fiscal Year</u>				
	<u>1978</u>	<u>1979</u>	<u>1980</u>	<u>1981</u>	<u>Total</u>
<u>ED & I</u>					
Professional:					
Physicists	4.5	5	5	2.5	
Mechanical Engineers	3	3	3	1.	
Electrical Engineers	3	3	3	1.	
Vacuum Engineers	2	2	2	1	
Control Engineers	2	2	2	1	
Cryogenic Engineers	1	1	1	0.5	
Civil Engineers	1	-	-	-	
Administration	<u>1.5</u>	<u>2</u>	<u>2</u>	<u>1</u>	
Total Professional	18	18	18	8	62
Non-Professional	<u>15</u>	<u>24</u>	<u>24</u>	<u>7</u>	<u>70</u>
Total ED & I	33	42	42	15	132
<u>Assembly & Machine Shop</u> (Non-professional)	4	26	34	13	77

TABLE VI-2

SUMMARY COST ESTIMATE
(Thousands of Dollars)

<u>Schedule A:</u>	Buildings and Utilities	2,945
	Improvement to land.....	100
	Utilities	860
	Construction	1820
	Equipment	165
<u>Schedule B:</u>	Storage Rings and Associated Equipment	9,030
	2-GeV Storage Ring.....	3515
	700-MeV Storage Ring	1175
	Injector System	980
	Associated Equipment.....	1560
	Experimental Equipment	1800
<u>Schedule C:</u>	E, D, & I	3,345
<u>Schedule D:</u>	Contingency	3,000
<u>Schedule E:</u>	Escalation	3,480
	T O T A L	21,800

TABLE VI-3

DETAILED COST ESTIMATE
(In Thousands of Dollars)

Schedule A: Buildings and Utilities 2,945

1.	<u>Improvement to land</u> ⁽¹⁾	100
	Preparation, grading, seeding	58
	Paving, curbs	42
2.	<u>Utilities</u> ⁽¹⁾	860
	Steam Service (L.S.)	45
	Water Service (150 ft. @ \$100)	15
	Sanitary Sewer (100 ft. @ \$50)	5
	Telephone (L.S.)	3
	Storm Sewer (1,800 ft. @ \$25)	45
	Fire Alarm (L.S.)	2
	Electric Utilities (L.S.)	115
	Special Power (L.S.)	150
	Trays and Special Conduit (L.S.)	50
	Machine Cooling (L.S.)	430
3.	<u>Construction</u> ⁽¹⁾	1820
	Main Building (47,500 SF)	1380
	Office-Lab Wing (6,250 SF)	250
	Mechanical Equipment House (5,000 SF)	190
4.	<u>Equipment</u>	165
	Laboratory Furniture	100
	Materials Handling Equipment	65

TABLE VI-3 (continued)

DETAILED COST ESTIMATE
(In Thousands of Dollars)

Schedule B: Storage Rings and Associated Equipment.....9,030

1. 2-GeV Storage Ring.....3515

Ring magnet system	1100
Magnet Power	220
Vacuum System	1060
Transport, inflection & bump coils	190
Low level electronics	210
Rf system	735

2. 700-MeV Storage Ring.....1175

Ring magnet system	365
Magnet Power	80
Vacuum System	330
Transport, inflection & bump coils	145
Low level electronics	140
Rf system	115

3. Injector System.....980

Reconditioned linac	215
Ring magnet system	270
Magnet Power	115
Vacuum System	75
Transport and inflection	50
Low level electronics	90
Rf system	40
Extraction	125

4. Associated Equipment.....1560

Controls	620
Wigglers and associated cryogenics	800
Shielding	140

TABLE VI-3 (continued)

DETAILED COST ESTIMATE
(In Thousands of Dollars)

5. <u>Experimental Equipment</u>	1800
Detectors & spectrometers	430
Monochromators: normal and grazing incidence, and crystal	440
Experimental data acquisition and control	480
General optical equipment	50
Beamline and station mounts, vacuum equipment, and local shielding	400
<u>Schedule C: Engineering, Design, and Inspection</u>	
132 man-years.....	3,345
<u>Schedule D: Contingency</u>	3,000
Buildings and Utilities @ approx. 15%	450
Storage Rings and Auxiliaries @ approx. 23%	2050
E,D, & I @ approx. 15%	500
<u>Schedule E: Escalation</u>	3,480
Buildings and Utilities	495
Storage Rings and Auxiliaries	2165
E,D, & I	820
T O T A L	21,800

(1) See Appendix A , engineering estimate sheets, for details

TABLE VI-4

Brookhaven National Laboratory

Project No. 78-CH-004

Synchrotron Radiation Research Facility
Schedule of Obligations (in Thousands)

	<u>FY1978</u>	<u>FY1979</u>	<u>FY1980</u>	<u>FY1981</u>	<u>Total Project</u> <u>Item</u> <u>Total</u>
A. Engineering, Design & Inspection Costs at 28% of Construction Costs	\$ 850	\$1,060	\$1,060	\$ 375	\$ 3,345
B. Construction Costs					11,810
1. Improvements to Land	100				100
2. Accelerator Building	1,380				1,380
3. Attached Laboratory Wing	250				250
4. Mechanical Equipment Wing	190				190
5. Machine Cooling	190	150	90		430
6. Machine Power Facilities	100	100			200
7. Utilities	100	130			230
8. Special Facilities	3,200	3,675	1,930	225	9,030
C. Standard Equipment					165
1. Laboratory Furniture and Equipment			100		100
2. Materials Handling Equipment			65		65
Sub-Total	\$6,360	\$5,115	\$3,245	\$ 600	\$15,320
D. Contingency on Above Obligations	765	1,200	965	70	3,000
E. Cost Escalation	885	1,315	1,050	230	3,480
Total Project Obligations	\$8,010	\$7,630	\$5,260	\$ 900	\$21,800
Appropriations Requested	\$8,500	\$8,500	\$4,800		

TABLE VI-5

SYNCHROTRON RADIATION RESEARCH FACILITY

ESCALATION, CONTINGENCY, & OBLIGATION FLOW ANALYSIS
(\$ in Thousands)

	<u>FY1978</u>	<u>FY1979</u>	<u>FY1980</u>	<u>FY1981</u>	<u>Total</u>
I. Escalation Factors					
Manpower @ 6%/yr. from FY 1976	.12	.19	.26	.34	
All other costs @ 8%/yr. from FY 1976 through 1st. qtr. of FY 1980	.12	.21	.24		
II. Base Estimate, Contingency, & Escalation Analysis					
A. Engineering, Design & Inspection					
Manpower Costs	850	1,060	1,060	375	3,345
Contingency @ 15%	115	150	165	70	500
Sub-total	\$ 965	\$1,210	\$1,225	\$ 445	\$3,845
Escalation @ 6%/yr.	120	230	230	150	820
B. Construction & Standard Equipment					
1. Buildings, Utilities & Standard Equipment					
Equipment	2,310	380	255		2,945
Contingency @ 15%	350	50	50		450
Sub-total	2,660	430	305		3,395
Escalation @ 8%/yr.	330	90	75		495
2. Special Facilities					
Assembly & Machine Shop Manpower	70	475	615	225	1,385
All Other Costs	3,130	3,200	1,315		7,645
Sub-total	3,200	3,675	1,930	225	9,030
Contingency @ 23%	300	1,000	750		2,050
Manpower Escalation @ 6%	10	95	165	80	350
Other Escalation @ 8%	425	900	490		1,815
III. Obligation Flow					
Base Estimate	6,360	5,115	3,245	600	15,320
Contingency	765	1,200	965	70	3,000
Escalation	885	1,315	1,050	230	3,480
Total Obligations	\$8,010	\$7,630	\$5,260	\$ 900	\$21,800

VII. OTHER CONSIDERATIONS

A. Codes, Standards, Quality Assurance

Codes, standards, and quality assurance as applied to the proposed Synchrotron Radiation Research Facility will fall into two major categories:

a) buildings and site, and b) the storage rings, linac, booster, and support equipment.

1. Buildings and Site

Construction will conform to applicable standards and codes set forth in ERDA General Design Criteria, Appendix 6301. Safety of personnel during construction is covered by Part 1910 (General Industry Safety and Health Regulations) and Part 1926 (Construction Safety and Health Regulations) of the Occupational Safety and Health Act, by ERDA Manual Chapter 0550, Operational Safety Standards, and by the BNL Safety Manual.

The model codes in use at BNL include the Uniform Building Code (International Conference of Building Officials), the National Electric Code (NFPA), and the National Plumbing Code (ASME). Codes of the American Society of Heating, Refrigerating, and Air-Conditioning Engineers (ASHRAE), the Air-Conditioning and Refrigeration Institute (ARI), and the Air-Moving and Conditioning Association (AMCA) will form an integral part of the mechanical specifications. The National Fire Codes (NFPA) are the guidelines for fire protection. Included in the aforementioned documents are material and test standards of the several accredited organizations.

All mandated codes and standards will be adhered to and careful attention will be given to the use of voluntary standards as a means of efficiently communicating design needs and implementing quality control. There are almost 600 construction-related standards and guides prepared or distributed by the American National Standards Institute. Wherever possible, these will be utilized. The "Recommended Design Practice Manual" of the

Metal Building Manufacturers Association will supplement the code in our building design. During the course of building design the staff will follow work now underway at the National Bureau of Standards, the Federal Energy Administration, ASHRAE and elsewhere so that recommendations for energy conservation can be incorporated.

Quality assurance for the building and site will be based on the following:

a) Understanding of site conditions. BNL will verify if soil mechanics properties at the site of the proposed building are similar to those at AGS where extensive data exist.

b) Proper design and placement of slab. BNL staff members will either design the slab, check the calculations of the building vendor if it is to be part of his contract, or hire a structural consultant for this purpose. The project staff will either prepare the specification or participate in the approval process. Records will be kept of material and mix certifications, strength tests, etc. BNL will have field personnel check the site before, during and after placement of concrete. The Laboratory will reserve the right to stop work if the contractor does not follow specifications.

c) Collaboration with pre-engineered metal building fabricator. BNL will determine the building size, minimum headroom, points of interference between equipment and structural members and location of doors, windows, and other architectural features. The Laboratory staff will also prepare performance specifications for HVAC, lighting, toilets, etc. The vendor will be responsible for code compliance. Prior to construction the vendor will submit the following documents for BNL approval:

- 1) Architectural drawings, including a list of materials of construction.

- ii) Structural calculations.
- iii) Specifications to subcontractors and equipment suppliers.
- iv) HVAC calculations.
- v) Lighting and plumbing layouts.

These documents will become part of the job file as well as built drawings, parts lists and maintenance manuals.

BNL engineers will coordinate the work of the building contractor with that of the excavation and slab subcontractors and those providing site utilities, roads and curbs, power and cooling water. The project staff will also provide field supervision and inspection.

2. Storage Rings, Linac, Booster, Support Equipment

The design, procurement, fabrication and placement of the myriad components that comprise the storage rings and experimental beam lines are so specialized as to be beyond much of the existing consensus-type standards. Extremely high levels of quality control are necessary and will be exercised because of required performance of many systems, coupled with their high initial cost and the cost of unplanned shutdowns. The Project Staff's approach to quality control will be made easier by Brookhaven's single responsibility for design, procurement, and installation of the rings and ancillary equipment. The Laboratory's long history of accelerator design, construction and operation has resulted in the compilation of a considerable body of specifications and design guides. Many of these can be readily applied to the proposed rings.

Quality control during design and development will include scheduling of design activities and assignment of responsibilities among the staff. A design and drawing file will be maintained for calculations and up-to-date prints. A system of design review will be undertaken so that criteria and alternate approaches can be evaluated for cost effective-

ness and confirmation to project objectives. Specifications will be prepared in conjunction with drawings that identify materials, describe manufacturing processes when necessary, and define the basis of acceptance and methods of testing. Wherever possible recognized standards of the ANSI, ASTM, AWS, ASME and others will be incorporated.

Quality control will be an integral part of procurement and fabrication procedures. Contract documents, including purchase orders, change orders, etc. will clearly identify the level of quality assurance expected from the vendor. This may include the submittal of one or more of the following documents:

- a) material certification and identification
- b) inspection and test reports
- c) process control data
- d) nondestructive examination
- e) as-built drawings
- f) cleaning, packaging and shipping procedures

Vendors will be chosen from a list of qualified bidders maintained by the Purchasing Division. Members of the Project Staff will have access to the vendor's plant during manufacture to inspect components or witness tests.

Quality assurance requirements for installation will begin with a procedure outlining the sequence of work and division of responsibilities for staging, handling, setting, aligning, cleaning, testing, inspecting and reworking subassemblies and systems. Complete records will be maintained for major systems listing final inspection measurements, repairs, as-built dimensions, etc.

Procedures will also be established for pre-operation testing and records kept of performance and modifications during these tests. Prior to full operation of the synchrotron, a maintenance program will be initiated. The program will be designed to ensure that project requirements are met by planned replacement of some components and overhaul maintenance of others. The maintenance policy objectives will be defined, spare parts identified, procured and stored, and a recommended timetable established for inspection and implementation.

B. Methods of Performance

It is proposed that the engineering, design and inspection of the building and utilities, as well as the award of competitively obtained lump-sum contract(s) for the construction work be done by Brookhaven National Laboratory. This appears to be the most practical and desirable method of accomplishment in view of the controls that Brookhaven must exercise in design and construction in order to minimize interferences with other programs at the Laboratory, and to assure that the requirements of ERDA with respect to safety and fire prevention are met. Brookhaven has the resources and experience in engineering, design, inspection, and contract management required for developing detailed specifications for erecting the pre-engineered steel building and installing utilities. Construction and procurement will be accomplished by fixed price purchases and contracts awarded on the basis of competitive bidding.

Engineering design of major components (magnet sectors, main vacuum chamber, rf cavities, etc.) will be performed by Brookhaven. Fabrication of these elements, as well as the provision of magnet and rf power supplies, cryogenics, control equipment, etc. where possible will be by commercial vendors on the basis of fixed price contracts awarded on the basis of competitive bidding. Assembly and testing will be performed by Brookhaven.

C. Environmental Protection Requirements

As presently conceived, construction and operation of this project will not generate any significant air or water pollutants except sanitary wastes which will be discharged into existing sewers connected to adequate treatment facilities or in areas of low population density, occupied intermittently, into septic tanks with leaching fields. The estimated cost of the project includes costs of those measures necessary to assure compliance with Executive Order 11752.

An environmental analysis is presently being prepared and will be available shortly.

D. Health and Safety

The principal health and safety risks associated with this facility are similar to problems that have been dealt with successfully at other BNL facilities. Adequate shielding will be established to limit the dose equivalent rates to 0.25 mrem/hr in accessible areas during normal machine operation. Additionally, the shielding will be sufficient to limit the total dose equivalent rates to 100 mrem or less in the event of complete beam loss at a single point. Induced radioactivity in machine components will not be a major problem. Electrical hazards associated with the R-F and other high voltage components will be protected within enclosure spaces and interlocked with both electrical circuits and key systems. Any storage capacitors will be equipped with automatic mechanical discharge devices. Fire detectors and a sprinkler system will be installed throughout the facility. Exits from the building will be in accordance with the life safety code.

APPENDIX A

BUILDING & UTILITIES ENGINEERING ESTIMATE WORK SHEETS

BUILDING SUMMARY OF J. H. LANCASTER'S ESTIMATES *

	\$ in Thousands		
	Accel. Bldg.	Office & Lab Wing	Mech. Equip. Wing
Foundations	31	6	6
Slab	211	9	10
Structure	475*	63*	40
Doors, etc.	11	4	5
Interior Finish	12	27	2
Electric	167	20	17
HVAC	356	45	25
Sprinkler	94	20	15
Toilets, etc.	13*	29	-
Floor Drains, etc.	-	27*	40
Steam Pit	-	-	10
Spec. Foundations	-	-	18
Total	1370	250	188
Sq. Ft.	47,500	6,250	5,000
Cost/Sq. Ft.	28.84	40.00	37.60
Use	29.00 <u>x 47,500</u> 1,377.5	40.00 <u>x 6,250</u> 250	38.00 <u>x 5,000</u> 190
Budget Numbers	1,380	250	190

* Adjustments to Lancaster's numbers are included to provide allowances for additional insulation, etc. for energy conservation and increased structural requirements, plus addition of lavatory facilities in the accelerator building and floor drains/safety showers/eye wash in the office/lab wing.

APPENDIX A - 2

SRRF Estimate 5/2/76
J. K. Conner, Inc.SITE WORK

		\$ K
<u>Stripping</u>	$340' \times 360' \times 1' \div 27 = 4600 \text{ CY} @ \$2.00/\text{CY}$	9
<u>Clearing</u>	$340' \times 360' \div 43,560 = 3 \text{ Acres} @ \$1000/\text{Ac}$	3
<u>Backfill</u>	$300' \times 300' \times 3' \div 27 = 10,000 \text{ CY} @ \$2.50/\text{CY}$ Assume 3' of backfill required over building area. This is somewhat conservative but necessary.	25
<u>Compact Backfill</u>	10000 CY @ \$1.00 CY Compact to density equal or greater than that of original soil	10
<u>Replace Topsoil</u>	$50' \times (300' + 300' + 300' + 300') \times 1\frac{1}{2}' \times \frac{1}{27} = 3400 \text{ CY} @ \2.00	7
<u>Fertilize, Seed</u>	$50' \times 1200 \text{ LF} \div 9 = 6700 \text{ SY} @ \$0.50/\text{SY}$	4
<u>Pavement</u>	West $45' \times 80' = 3600$ $25' \times (55' + 40' + 40') = 3375$ North $25' \times 100' = 2500$ South $25' \times 90' \times 2 = 4500$ East $275' \times 65' = 17875$ $31850 \div 9 = 3600 \text{ SY} @ \8.50	31
<u>Side Wall</u>	$(40' + 50') \times 6' = 540 \text{ SF} \times \$1.20/\text{SF} = .648^K$	1
<u>Curbing</u>	On Main Entrance only 2 times $(70' + 70' + 80' + 20' + 20' + 40' + 25') = 420 \text{ LF} \times \$50/\text{LF}$	7
<u>Gravel Fill</u>	between Curb on Technology $140' \times 12' = 1680 \text{ SF} \times \$1.20/\text{SF}$	2

UTILITIESSteam

Connect to Manhole NE corner of Brookhaven and Technology
 Manhole Piping Say \$5000 5
 Underground Run 170 LF x \$175/LF 30
 including trenching
 Steam Reduction Station in Building Say \$2000 8

Water

Connect to Technology Street ? 15
 Cut into existing main, valve \$1,000 + \$1000 2
 Run to building 150' x \$7/LF = 8" CA. 1.1 } 11
 Trench & Backfill 150' x 3' x 5' ÷ 27 = 83 cy @ \$10/cy = 8.3 }
 Path roadway .7 }
 Valving for Sprinkler System 2

Sanitary Sewer

Connect to M.H. on Technology Street 4
 100 LF x \$10/LF = 1,000 1
 100 LF x 3' x 5' ÷ 27 = 56 cy @ \$10/cy 1
 Clean out Manhole check line 2

Telephone

No information 3
 Assume duct bank on Brookhaven - 31st Precinct
 180 LF @ 4.50 = \$8.10 1
 180 x 3 x 5 ÷ 27 = 100 cy x \$10/cy 1
 Reel etc inside building 1

Storm Sewer

Run 12" line around building 45
 $300' + 340' + 300' + 180' + (3 \times 20') + (4 \times 20') + (2 \times 20') + 230' = 1920'$
 $1920 \text{ LF} \times \$16/\text{LF} = 31$
 Trench $1920 \text{ LF} \times 3 \times 5 \div 27 = 1066 \times 10/\text{cy} = 11$
 Assume 4 Manholes @ \$600 ea 3

Electric

Tap a 704 Feeder - 113
 5.0 MVA installed 2. transformer 25/3.1 @ 45 ea 90
 Duct Bank from nearest manhole on Technology Street
 $300 \text{ LF} @ \$8/\text{LF} = 2400$
 $2400 \times 3 \times 5 \div 27 = 167 \text{ cy} @ 10 = 17$
 Cable $600 \text{ LF} + 400 + 300' = 1300 \text{ LF} @ \$13/\text{LF} = 17$
 Assume one Manhole @ 1500 ea 2

Fire Alarm

200 LF @ 2.00/LF thru telephone Duct 1

BUILDINGBuilding Foundation:

$$\begin{aligned} \text{Volume } 1.3 \times 1.3 \times 2 &= 3.4 \\ 3.0 \times 3.0 \times 1 &= 9.0 \\ \text{Volume} &= 12.4 \\ &= .46 \text{ cy} \end{aligned}$$

\$ K
\$ 41'

$$\text{Area Bottom } 25 \times 50 = 1250 \text{ SF} \times 30 \text{ \#/SF} = 37500 \text{ \#} \div 5000 \text{ \#/cy} = 7.5 \text{ SF}$$

$$\begin{aligned} \text{Number of Footings } 12 + 12 + 12 + 11 + 11 &= 58 \\ 58 \times .46 \text{ cy} &= 27 \text{ cy} @ \$250/\text{cy} = \$6750 \\ \text{Excavation Footing } (10 + 7 + 7) &= 24 \text{ ea} \times 3' \times 5' \times 5' \div 27 \times 10/\text{cy} = 670 \\ \text{Smooth Bottom } 58 \text{ ea} \times 1/5 \text{ ea} &= 670 \\ \text{Grade Beam } 275 + 200 + 250 + 100 + 23 + 100 &= 950 - (185) \\ 125 + 50 + 50 &= 225 - (44) \\ 100 + 50 &= 150 - (29) \\ &= 1325 \text{ LF} \end{aligned}$$

$$\begin{aligned} 3 \text{ CF/SF} \\ 1325 \times 3 \times \frac{1}{27} &= 148 \text{ cy} \times \$175/\text{cy} = 26 \end{aligned}$$

$$\text{Office Wing Cols } 6 \text{ Footings} \times .46 \text{ cy} = 3 \text{ cy} \times \$250/\text{cy} = 750$$

$$\text{Excavation Grade Beam inc Backfill } 1325 \times 3 \times 3 \div 27 = 442 \times \$10/\text{cy} = 4420$$

Building Slabs

Compaction and Backfill in Site Work
Main Building 47,500 SF 12" thick w/Heavy

$$\text{Highway mech at top and bottom } 47,500 \times 1 \times \frac{1}{27} = 1760 \text{ cy} \times \$120/\text{cy} = \$211,000$$

$$\begin{aligned} \text{Concrete } 12" \text{ Slab } 2.20/\text{SF} \times 27 &= 60/\text{cy} \quad 60 \quad 60 \\ \text{Steel Mesh } 4" \times 4" \text{ wire } 55 \text{ \#/SF} &= 50 \text{ \#/SF} \times 2 = 1.00/\text{cy} \\ 1.00 \times 27 &= 27.00/\text{cy} \quad 27 \quad 50 \\ \text{Finish } @ 32.5 \text{ \#/SF} \times 27 &= 877.5 \\ \text{Total} &= 96/\text{cy} \quad 119 \\ \text{Cure} &= 110/\text{cy} \quad 120 \end{aligned}$$

$$\begin{aligned} \text{Tie } 1" \text{ Bars @ } 12" \text{ T\&B } 1" \text{ No } 8 \quad 2.67 \text{ \#/SF} \\ \text{Per SF } 2.67 \times 2 &= 5.34 \text{ \#/SF} \times 27 = 144.22 \text{ \#/cy} \\ \$700/\text{ton installed or } 35 \text{ \#/ton installed} &= \$50/\text{ton installed} \end{aligned}$$

$$\text{Office Wing } 6250 \text{ SF} \times \frac{1}{2} (4" \text{ slab}) \times \frac{1}{27} = 77 \text{ cy} \times \$110/\text{cy} = \$8500$$

$$\text{Mechanical Room } 5000 \text{ SF} \times \frac{1}{2} (6" \text{ slab}) \times \frac{1}{27} = 93 \text{ cy} \times \$110/\text{cy} = \$10,135$$

BUILDINGMain Building

Use Means 1976 Cost Estimating Guide
Page 287 Marked up 12% for New York
and 18% for O.H. & Profit $1 \times 1.18 \times 1.12 = 1.32$
Same 20' height.

\$ K

Making Cost 200' width part of Room $2.00/SF \times 47,500 = \$95,000$

Erection cost Roof & Frame $.80 \times 47,500 = 38,000$

Wall $20 \times 950 LF$ $19000 SF \times .45$

$8,600$

$\$141,600$

For New York $\times 1.32$

$\$186,900$

Cost per Square Foot

$\$3.93/SF -$

Cost of Liner $19,000 SF @ 1.00/SF$

$19,000$

$.40/SF -$

Try On-all Total Cost given on Page 287

$\$47,500 SF$

Total Cost Basic Bldg inc erection $2.75/SF$

$130,600$

$1\frac{1}{2}$ " insulated siding

$.40/SF$

$19,000$

Panel Finish $19,000 SF @ 18\%/SF$

$3,420$

$153,000$

For New York $\times 1.32$

$202,000$

Cost per square foot

$\$4.25$

NOTE See Sheets

Use Median of $8.00/SF$

Cost $\$8.00 / SF \times 47,500 = \$380,000$

$\$380 -$

Interior Finish Paint Floor 2 Coats Floor Enamel
 $47,500 SF \times .25 / SF = \$11,875$

12 -

No finish painting on Structural Steel - Linc. Pr-finished

Overhead Doors

Steel Rolling w/operator

4 each - 12×14 OH Doors $@ \$2000 ea$

8

11 -

8 each 3×7 Doors $@ \$350 ea$

3

Electric Lighting

Fluorescent lighting & duplex Recept

Use $\$3.50 / SF \times 47,500 / SF = \$166,250$

$\$167$

Heating Ventilation and Air Conditioning

Single Room Use either Unit heaters & Coolers or Ductwork

Use $\$7.50 / SF \times 47,500 SF = \$356,250$

356

Sprinkler System

Open Area

Use $\$1.75 / SF \times 47,500 SF = \$83,125$

34

Value etc.

10

Total including Concrete Slab
Cost per Square Foot

$\$1231$
 $\$25.92 / SF =$

Try HVAC for PEP way
 $47,500 \text{ SF} \div 300 \text{ SF/ton} = 158 \text{ tons}$

$158 \text{ tons} @ \$2500/\text{ton} = \$395,000$ (Close Enough)

\$ K

4 LKS
OFFICE WING

Structure

12' Fan height
 $6250 \text{ SF} @ \$8.00/\text{SF} = \$50,000$

50'

Interior Finish

Floor $5000 \text{ SF} @ \$0.75 = 3750$
 $1250 \text{ SF} @ \$0.25 = 312$
 $\$4062$

4'

Partitions $\$12,375$
 $7450 \times 350 \times 200 = 550 \text{ LF} \times 10 = 5500 \text{ SF} @ \$2.25/\text{SF}$

13'

Hung Ceiling $5000 \text{ SF} @ \$0.75/\text{SF} = 3750$

4'

Painting Partitions $11,000 \text{ SF} @ \$0.40/\text{SF} = 4400$

5'

Doors: Say $20 @ \$200 \text{ ea} = 4000$

4'

Windows: Say $8 @ \$100 \text{ ea} = 800$

1'

Electric Lighting $5000 \text{ SF} @ \$3.50/\text{SF} = 17500$
 $1250 \text{ SF} @ \$2.00/\text{SF} = 2500$

20'

Heating, Ventilation & Air Conditioning

$5000 \text{ SF} @ \$8.00/\text{SF} = 40,000$
 $1250 \text{ SF} @ \$4.00/\text{SF} = 5,000$

45'

Sanitary System

$6250 \text{ SF} @ \$2.25/\text{SF} = 14062$
 Valves etc

15'

5'

Toilets, Fixtures $2U + 2WC + 2L > 10 \text{ ea} @ \$2,000/\text{compr} = 20$
 $2WC + 2L$

23'

Accessories $2 @ 500 = 1$
 Partitions $5 @ 300 = 2$

Drinking Fountains $3 @ \$600 = 1800$

2

2'

Hot Water Heater $1 \text{ ea} @ \$1,000$

1'

Ceramic Tile Floors $300 \text{ SF} @ \$4.00/\text{SF} = 1200$
 Wainscot $80 \text{ LF} \times 4 = 320 \text{ SF} @ \$250 = 800$

3'

Total Including Concrete Slab
 Cost per SF

$\$204$
 $\$32.64/\text{SF}$

MECHANICAL EQUIPMENT ROOM

		\$ K
<u>Structure</u>	20' Eave Height 5000 SF @ \$8.00/SF = \$40,000	40
<u>Overhead Doors</u>	2 - 12' x 14' Steel Rolling @ \$2000 ea	4
<u>Interior Finish</u>	Paint Floor 5000 SF @ \$.25/SF = \$1250	2
<u>Electric Lighting</u>	5000 SF @ \$3.50/SF = 17,500	17
<u>Ventilation & Heat</u>	5000 SF @ \$5/SF Large Roof fans, Unit Heaters, Louvered intakes	25
<u>Man Doors</u>	2 each @ \$350 ea/hardware = 700	1
<u>Sprinkler System</u>	5000 SF @ \$1.75/SF = 8750 Valves 1500	10 5
<u>Condensate Return Pumps</u>	L.S.	10
<u>Special Concrete Foundations</u>		
	Chillers 2	
	CW Pumps 2 Say 12 @ \$1500 ea approx	18
	Air-Strainers 3	
	H ₂ Comp 2	
Total including slab Cost per SF		132 29,400 / 12 =

SPECIAL ELECTRIC

Heavy Power Distribution	To Panels	40
	4 Motor Control Centers @ 150	60
	From MCC to Equipment	50

SPECIAL PLUMBING

Floor drains in Mechanical Room	20
Drain to Storm Sewer	20

SRRF Estimate
J. H. Lawrence

5/23/76

RADIATION SHIELDING

Main Ring 250v 450 LF
 Booster 35m 124 LF
 700kV 44m 150 LF

Cost of Shielding, Ordinary Concrete
 Inc Lifting Eyes
 @ \$160 / CY

$$2 \times 7 \times 2 = 28$$

$$1 \times 1 \times 9 = 9$$

$$\frac{37 \text{ LF}}{1.37 \text{ CY/LF}}$$

Main Ring
 450 LF $\times 1.37 \text{ CY/LF} = 616.5 \text{ CY} @ \$160/\text{CY} = 98,650$

\$100

Booster Not Included
 124 LF $\times 1.37 \text{ CY/LF} = 169.9 \text{ CY} @ 160/\text{CY} = 27,170$

~~25~~

700kV Ring Not Included
 150 LF $\times 1.37 \text{ CY/LF} = 205.5 @ \$160/\text{CY} = 32,880$

~~35~~

Rebar Steel Lead and Puffin

20

Rebar Dump

20

Total

140

Source Herb Anderson formerly with White Construction
 Now with Brotherton Construction Corp
 185 Atlantic Street
 Hackettstown, N.J. 07601
 Tel 201-487-8148

He said a good estimate for the base blocks
 would be \$120/CY to which he has to be
 added the sleeves, lifting attachments,
 painting, delivery and installation.
 Also more for small sandwich block Est.
 Say \$160/CY

\$120/CY

\$40/CY

\$160/CY

No corner Protection

Sprinkler Systems

Armco

Stran-Steel

Butler

HMA Bars

offset

No Price

\$1.00/SF

\$1.00/SF

\$1.25/SF

Try Means

By 210

Net System

Open Piping

$$560/\text{head} \times 1.30 = 728/\text{head}$$

$$\text{Area} = \frac{1}{100} \times 728 = 7.28/\text{SF} \quad \text{Use } 1.75$$

$$\text{offset Area} = 120/\text{head} \times 1.30 = 156$$

$$\frac{1}{100} \times 156 = 1.56/\text{SF}$$

$$\text{Use } 2.25$$

Add for Flow Valves.

Machine Cooling

Accept W. Walker & R. Brown Equipment List

131^K

Main Headers

150^K

$$\text{Manifolds } 2\frac{1}{2} \text{ in } \frac{450 \text{ LF}}{50} = 9 \quad 10$$

$$\text{Pneumatic } \frac{124 \text{ LF}}{50} = 3 \quad 4 > 18 @ \$1000 \quad 18$$

$$\text{7000 in } \frac{150}{50} = 3 \quad 4$$

Installation

18 @ 200

4

Installation of Equipment

20% of 131

30

Evap for Bldg 4/c

50

Misc Controls, Elec Hook-up etc

50

433

430

50

Allowance for Trays, special conduit etc atCeiling level for distribution of secondary wiring,
Controls etc

5/24/76

Data on Butler Buildings
System Structures Inc.

Petrie Stem

HA7-9600

We missed on dimensions and Stem had a slightly larger building than I had

Landmark Building	All 24' Eave height	even office
Seamed Roof	convect/leak	
50' Bay spacing x 30' bay	$200 \times 270 =$	54,000 SF
L Shape	$100 \times 30 =$	3,000
Mechanical Space	$50 \times 90 =$	4,500
Office Space	$50 \times 120 =$	6,000 SF
	Total	67,500 SF

Monopanel used throughout - Two 26 ga steel sheets with 2" fiberglass insulation between U = .15 wall Cost \$2.50/SF installed
This eliminates the interior girts

Union contractors - Davis - Reason wages

Erected Cost \$400,000 complete \$5.92/SF

This is shell complete

Roof 2" insulation 26 Ga Sheet U = .12

Roof Loading High Bay 30' LL - 20' wind
Office 50' LL - 20' wind

Dry \$6.00/SF

12' x 14' Rolling steel doors with elec operator \$1,800 each
3' x 7' Man doors 300 "

H, V & A/c Office $6,000 \text{ SF} \div 300 \text{ SF/ton} = 20 \text{ tons} @ \$1,000/\text{ton} = \$20,000$
High Bay $57,000 \text{ SF} \div 250 \text{ SF/ton} = 228 \text{ tons} @ \$1,000/\text{ton} = \$228,000$
= \$4,000/SF

Electric Lighting Office \$2.00/SF
High Bay \$1.25/SF

Plumbing \$1,000 per fixture unit includes drains

Sprinklers $57,000 \div 100 \text{ SF/head} = 570 \text{ heads} \times \$85/\text{h} = \$48,450$
= .85/SF

HE recommended \$1.25/SF for Office
1.00/SF for High Bay Areas

Crane Estimate

Interior Steel Columns $700 \times 30 = \$3,000$
Crane 5 ton \$15 - 20,000 each
Crane Runways 5-6,000 each

SRIF Estimate 7/24/70
JH LancasterData Stran Steel Building
Lindquist Construction Company
Setauket

Mr David Mills

Telephone 751-0653

Building dimensions as shown on Sheet

Insulation 3" thick standard on walls & roof U = .10

Walls 26 ga sheets with liner to 12'± height

Roof 26 ga sheets

Design 30" hh and 20" Wind Load

Doors 12'x14' with electric operator 4 in high bay 2 in High Rm

Includes gutters and downspouts

Union contractors - Davis - Queen wage scale

Cost	Basic Building	\$ 8.00 /SF
	Electric	4.00 /SF
	HVAC	3.00 /SF
	Turn-key total	\$15.00 /SF
	Sprinkler System	Use \$.75 per head 1.00 per SF
	Plumbing Fixture	\$ 350/unit Non-Union \$1000 Union

\$8.00/SF

Bridge Crane -

No Price

Building will only hold one - I couldn't get a
rational explanation of this.

SRIF Estimate 5/24/76
StammarOrder from Arco Steel Company
W.J. Riley & Co

Mr Sterzel

HUB - 2280

Building size as shown on Sheet No _____

Design 30 #/sq ft LL and 20 #/sq ft wind load

Insulation Standard is 2" on walls & roof

Cost \$.35/sf

U Factor

Bays are 24' and 28' standard

Walls 26 ga wall covering

Liner 26 ga up to 12' height

O.H. Doors 12x14 Rolling Steel w/operator \$ 8.00/sf

Man Doors 3x7 Steel

Gutters & Downspouts

\$ 3.50/LF

\$ 1.00/sf Encl

\$ 1350. each

\$ 275. ea

\$ 3000 for Building

Costs

Structure completely

Material
Erection

\$ 6.00/sf

\$ 2.50/sf

\$ 8.50

20% Add for Union Erection

Total

1.70

10.20/sf

\$ 10.20 SF

Lighting 8' Fixtures continuous
rows @ 12' c to c w/panels

1.00/sf

HVAC

5.00/sf

\$ 16.00/sf

Crane Understring 5 ton \$ 12,000 each
Steel needs strengthening
Runways need to be added