SPEAR
3 GeV Booster Synchrotron

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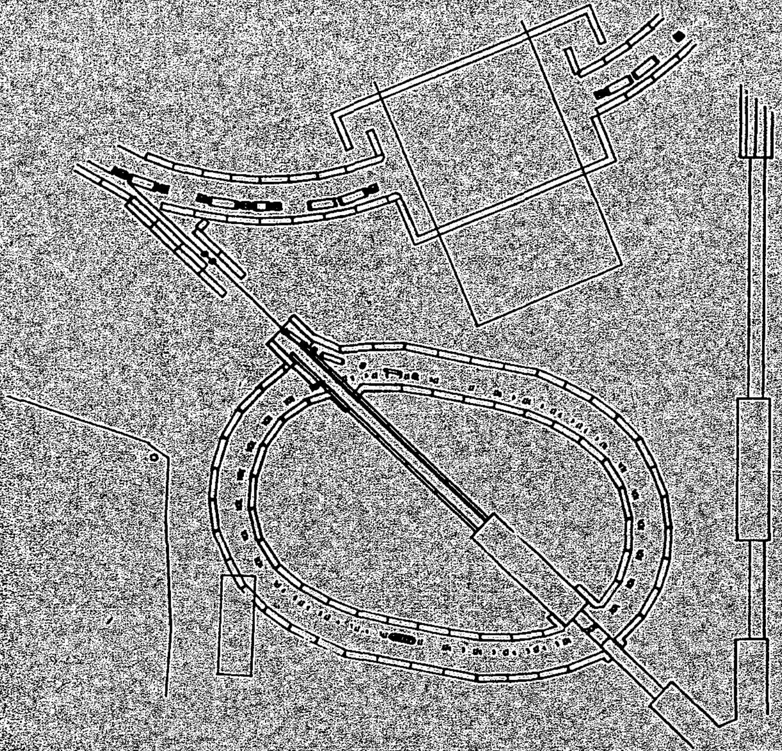

August 1987

Stanford Synchrotron Radiation Laboratory, SSRL

Stanford University, Stanford, California 94305

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3 GeV
BOOSTER SYNCHROTRON
for SPEAR

Conceptual Design Report

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Stanford University, Stanford, California 94305
Prepared for U.S. Department of Energy under Contract # DE - AC03 - 82 ER 13000

CONTENTS

1. INTRODUCTION 1

1.1 Overview 1
1.2 Rational for a Dedicated Synchrotron Booster Injector 6
1.3 Review Process for the Injector 9
1.4 R & D Effort for this Injector 11

2. GENERAL DESCRIPTION OF INJECTOR AND PARAMETERS 12

2.1 Performance Goals 12
2.2 General Design Concept of the Injector 14
2.3 Injection Process 16

3. CONCEPTUAL DESIGN OF INJECTOR SYSTEM 17

3.1 Lattice Design and Beam Characteristics 17
3.2 Technical Components 27
  3.2.1 Preaccelerator Linac 27
  3.2.2 Magnet System 35
  3.2.3 Acceleration System 48
  3.2.4 Vacuum System 51
  3.2.5 Instrumentation and Controls 54
  3.2.6 Injection and Ejection 57
  3.2.7 Utilities 58
3.3 Shielding and Support Buildings 60
3.4 Safety 63

APPENDIX 64

INTRODUCTION

1 Introduction

1.1 Overview

Synchrotron light can be produced from a relativistic particle beam circulating in a storage ring at extremely high intensity and brilliance over a large spectral region reaching from the far infrared regime to hard x-rays. The particles, either electrons or positrons, radiate as they are deflected in the fields of the storage ring bending magnets or of magnets specially optimized for the production of synchrotron light. The synchrotron light being very intense and well collimated in the forward direction has become a major tool in a large variety of research fields in physics, chemistry, material sciences, biology and medicine.

The first SLAC storage ring enhanced for synchrotron radiation research was the SPEAR ring. This development began in 1972, with the first beam line becoming operational in mid-1974. SPEAR has a 234 meter circumference and operates at energies up to 3.5 GeV with currents up to 100 milliamps. The storage ring can accomodate 16 insertion device beam lines (not including all bending magnet beam line possibilities) without interference with a high physics energy experiment operating in the ring's West Pit. Additional beam lines can be implemented upon the completion of the high energy physics program.

Although SPEAR's emittance, 460 nm-rad at 3 GeV, for the regular mode of operation is larger than those of the most modern synchrotron radiation sources, a low emittance configuration, with a design emittance of 130 nm-rad, was tested in 1984. The existing SPEAR injection system, however, makes its utilization on a day-to-day basis difficult because of limitations in the present injection configuration. Modifications of the injection system are described in this Conceptual Design Report.

At present, SSRL operates 21 experimental stations on nine beam lines on the SPEAR storage ring. In the next two years, one more beam line (X) and one station will be added to SPEAR. A layout of the SPEAR facilities is shown in Figure 1. The experimental stations of SSRL are used by more than 500 scientists from 99 different institutions in 32 states and 11 foreign countries. These institutions include 51 universities, 15 private corporations and 12 government laboratories.

Particle beams usually circulate in the ultrahigh vacuum environment of a storage ring for several hours. After the beam current has decayed to a low value new particles are injected from a separate accelerator referred to as the injection system.

Injection of particles into the SPEAR storage ring has been traditionally performed from the existing 2 mile linear accelerator at the SLAC. This injector has been specified and designed for very high particle energies and is too big an injector for a 3 GeV storage ring. To obtain reasonable injection efficiencies it is necessary to accelerate the particles in the linear accelerator to about 10 to 15 GeV and then decelerate them again to the low injection energy of 2.3 GeV. This sequence of acceleration and deceleration is necessary to assure that a significant amount of particles survive the electromagnetic interaction with the accelerator sections while traveling over 2 miles during acceleration. As a result of this complicated acceleration process it has been difficult to run the injector in a reproducible way and injection into SPEAR has been less reliable than is desirable or readily achievable.

This situation is expected to get aggravated in the SLC phase of operation which started in fall of 1986. In this mode of operation intense bunches of positrons and electrons are accelerated in the SLAC linear accelerator to energies up to about 50 GeV. After acceleration they are guided through two transport lines, one for the positron bunch and one for the electron bunch, which after 1400 m aim at each other. At that point both the electron and the positron bunches collide and produce the high energy reactions to be studied by the high energy physics community. During this mode of operation of the linear accelerator low energy injection into SPEAR is highly interruptive for the high energy physics program and as a consequence, only two SPEAR fills per day are planned to be available. With this schedule still the high energy physics program is interrupted for 2 hours every 12

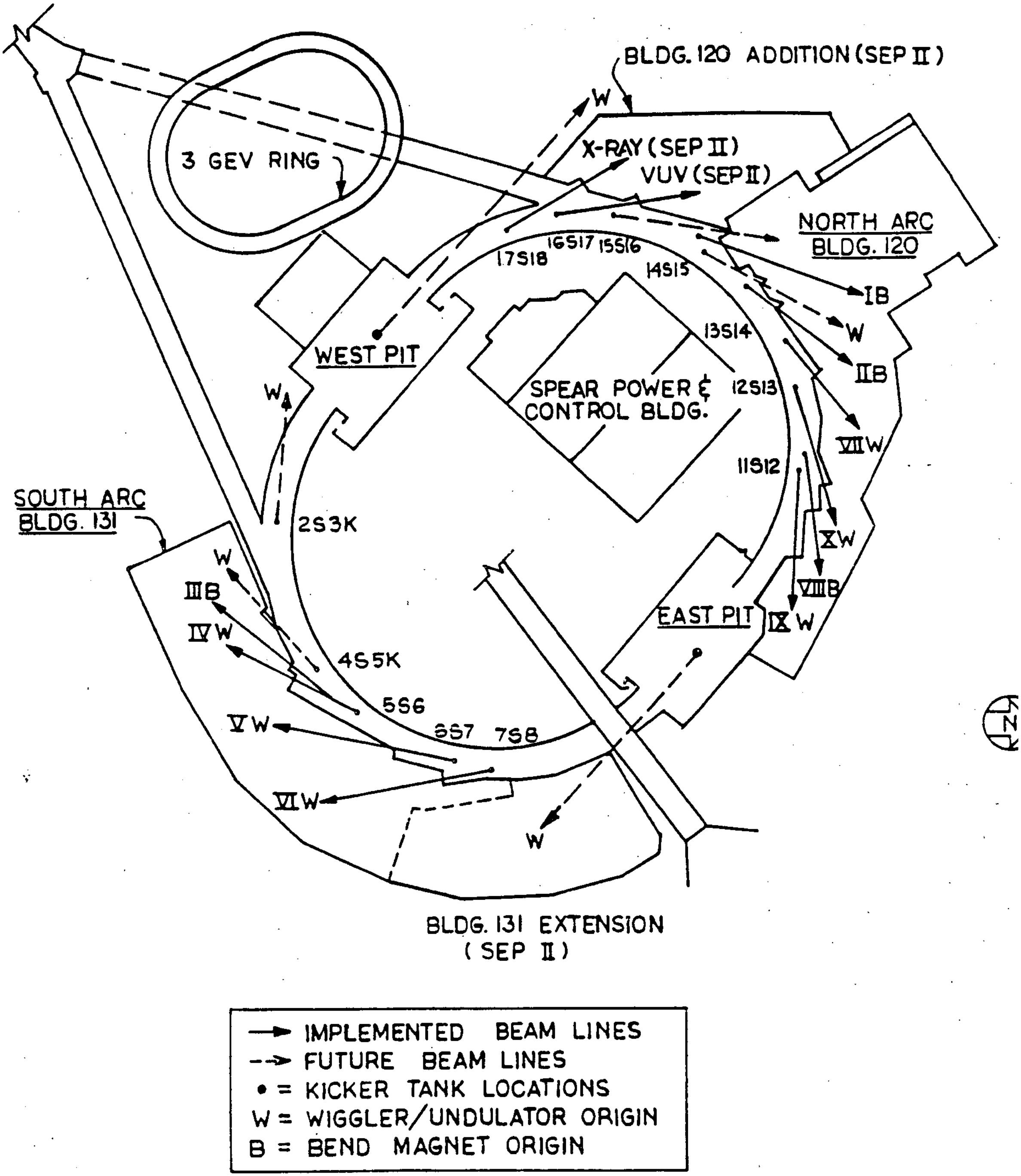

Fig. 1: Layout of the SSRL Facilities at SPEAR

hours. The running costs of the linac during these two hours are very high for SSRL since the linac must be kept operating at full power so as not to change the delicate thermal balance in the accelerating sections for SLC operation.

This schedule greatly limits the synchrotron radiation experimental program at SSRL. To keep SPEAR operating at a high performance level and develop improvements, machine physics shifts must be available. For such machine developments it is crucial that on-demand injection be available. In the SLC era, however, this is not the case and if the beam is lost during machine physics the efforts are stopped until the next 12 hourly scheduled injection. This makes machine physics experimentation and scheduling extremely inefficient.

The nature of this interruption comes from the required precision control of the SLC beams at 50 GeV. To accelerate the very high intensity beams during SLC operation many strong quadrupoles are required along the linear accelerator to prevent a beam break-up. These quadrupoles are much too strong to allow the passage of a 2 to 3 GeV beam for SPEAR and, therefore, must be turned off. While this is not a problem for SPEAR injection, it takes considerable time to recover from SPEAR injection back to SLC operation. This is because it generally is difficult to reproduce exact beam conditions after magnet strengths have been changed. Recovery from machine physics runs at PEP as well as at SPEAR traditionally have been difficult because of this reason. A change in the injection energy at SPEAR and at PEP is therefore done very rarely. A change in the injection energy requires at least several hours to be set up. For the SLC to obtain beam collision again after a SPEAR injection, the position of the electron as well as the positron beam must be reproduced at the end of the 2 mile linac to 0.1 mm and an angle of 1 microradian.

Consequently, dedicated injector for SPEAR appears to be the proper facility to both preserve the goals of the high energy physics community with the SLC and to assure the availability of photons for the synchrotron radiation user community. In addition such a dedicated injector can be optimized for SPEAR injection alone and therefore can provide greatly improved injection conditions. Since the operating costs of this injector will be much less than those for the 2 mile SLAC accelerator, SSRL should be able to provide synchrotron radiation for a much larger fraction of the year than it can now.

In this Conceptual Design Report, CDR, an injection system which would allow the accumulation of electrons into SPEAR at an operating energy of up to 3.0 GeV is described. To obtain optimum performance of a storage ring dedicated to the production of synchrotron radiation a full energy particle injector is highly desirable. That is, means the particles are injected into the storage ring at the operating energy. The feature of full energy injection provides several advantages. All storage ring components are left in their running conditions during injection since it is not necessary to change the storage ring energy from the operating energy to the injection energy. If the injection energy were different from the operating energy the excitation of the ring magnets would have to be changed for injection and a special magnet training routine must be followed to establish the desired magnetic fields again in the presence of hysteretic effects. For a large number of experiments it is very critical, however, to keep the photon beam as stable as possible over a long period of time which is very difficult to achieve when magnetic fields in the storage ring must be changed. In case of a full energy injection the photon beam steering is done once and will stay adjusted over many shifts.

For economic reasons often an injection energy lower than the operating energy of the storage ring is chosen. In case of a full energy injector, however, higher beam currents can be stored in the storage ring than would be possible at lower energies. All known instabilities allow higher storage ring beam currents to be reached as the beam energy is increased. Moreover, since magnet field training is not necessary the remaining beam current from the previous fill is not lost, the time for beam injection is reduced and the efficiency of the storage ring for the production of synchrotron radiation is significantly enhanced.

1.2 Rational for a Dedicated Synchrotron Booster Injector

To obtain full energy injection different types of injectors can be utilized. In particular, a linear accelerator as well as a booster synchrotron can serve as such a full energy injector. In this proposal a booster synchrotron is proposed in order to take advantage of several favorable features with respect to a full energy linear accelerator. To achieve a beam energy of one GeV or higher a booster synchrotron can be constructed at a significantly lower cost than a linear accelerator.

With present day technology a 3 GeV linear accelerator would require at least 30 accelerating sections, each 10 feet long, and one 100 MW klystron for each of these sections. This type of klystron has been developed at SLAC for the SLC project and is not available yet from industry. With 35 MW klystrons, which are available from industry, the linac would require 51 stations to reach 3 GeV. The length of such linacs would be 120 m or 190 m respectively and thereby longer than the circumference of the proposed booster synchrotron. The space available next to SPEAR would not allow the placement of such linacs. The costs for such linacs has been estimated to be more than twice the cost of the equivalent components in a booster synchrotron. In addition the operating and maintenance costs are significantly higher for a linear accelerator than for a booster synchrotron. Assuming a 20,000 hour lifetime on average for each klystron and a running time of 5,000 hours per year, 7.5 klystrons must be replaced every year at a cost of more than $400K. In contrast the proposed booster involves only four klystrons, three lower power linac klystrons and one DC klystron for the synchrotron itself.

For these reasons it has been decided to propose a 3 GeV booster synchrotron as a dedicated injector into SPEAR. Such a booster fits well in the space available next to SPEAR (Figure 2).

The technology involved in the construction of a synchrotron is similar to that of the storage ring and therefore the operation and maintenance of both rings is simplified which enhances its reliability. Of course, in the case of a synchrotron, a preinjector in the form of a small linear accelerator or microtron is needed. In this proposal a three section linac is assumed

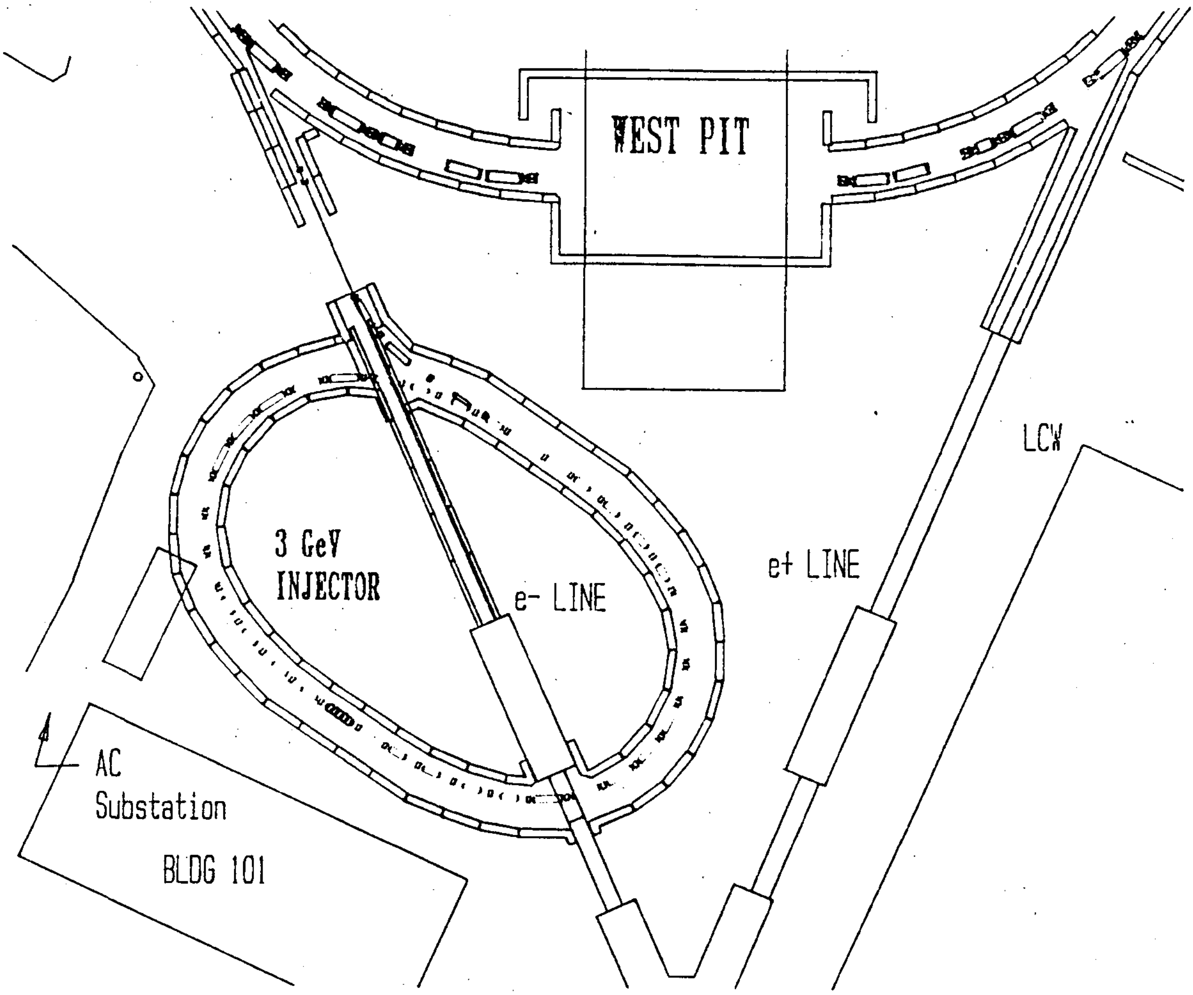

Fig. 2: General Layout of the Injector - SPEAR Complex

which is much easier to operate and maintain. The beam characteristics for a preinjector linac to inject into a booster synchrotron are very much relaxed compared to injection into a low emittance storage ring.

In a linac/synchrotron injection system full energy injection is assured virtually at all times. If a full-energy linear accelerator is used, a loss of any klystron reduces the energy of the linac and therefore the injection energy into the storage ring is reduced until this klystron is replaced. In the proposed scheme the loss of one linac klystron would only reduce the injection energy into the synchrotron from the preinjector which, however, has no effect on the ultimate energy the synchrotron can reach. The only detrimental effect would be some increase in the storage ring injection time since the synchrotron probably would no longer be able any more the same beam current at the reduced preinjector energy. The operating parameters of the storage ring, however, need not be altered.

Of course, the loss of the synchrotron klystron would prohibit any further acceleration and injection. In this proposal we have therefore assumed that the RF system be the same as for the storage ring so that RF components and spares can be shared.

In addition to these operational and maintenance considerations it should be noted that injection into a booster synchrotron from a linear accelerator is much easier than direct injection from a linac into a low emittance storage ring. This is because a much simpler solution for the focusing lattice in the booster synchrotron can be chosen. The beam in such a lattice does not require the tight magnet field and alignment tolerances of a storage ring and allows for a larger physical and dynamic aperture. This significantly reduces the quality of the beam required from the linac preaccelerator and makes the operation of the short preinjector system relatively easy.

On the other hand, for injection into a high brilliance storage ring with limited aperture the injection system must provide a beam of high quality. Beam parameters like beam energy, beam size, and energy spread must be closely controlled for successful injection. This requires a powerful control system if direct injection from a high energy linac is desired. In a synchrotron the beam size and energy spread are determined by the design of the lattice and are therefore well known while the beam energy itself is well defined and controlled by the fact that the synchrotron acts like an energy defining spectrometer. In a linear accelerator these parameters can vary greatly if not closely controlled at all times.

Even in a well adjusted linear accelerator the beam parameters are ultimately determined by the source characteristics. Therefore, should it become desirable to use positrons in the storage ring it would be difficult to obtain a high injection efficiency with a linac injector because of the large positron beam emittance which is a consequence of the production process. The beam emittance and energy spread is well determined in a a synchrotron due to synchrotron radiation damping, and independent of the nature of the particles or their sources. Both quantities can be made equal and significantly smaller in a booster synchrotron than in a linear accelerator to facilitate injection into the low emittance storage ring.

In this proposal the synchrotron lattice has been designed for a relatively small beam emittance to provide easy injection into the storage ring. The general design concepts for the 3.0 GeV booster synchrotron are described in the following sections of this CDR.

1.3 Review Process for the Injector

In late 1985 it became more and more apparent that the filling of the SPEAR storage ring would cause major interference with the SLAC SLC program since it requires a reconfiguration of the SLAC linac. To recover from this linac reconfiguration is time consuming and therefore costly both from an economic and a scientific point of view. With only two fills per day the interruption of the high energy physics program would be 2 hours for each fill or 16.7% of the time would not be available for high energy physics because of the filling of SPEAR. Moreover the linac cannot be operated for most of the year for fiscal reasons.

To protect SSRL's research program the SSRL directorate decided to propose a dedicated injector for SPEAR. After internal reviews the proposal was discussed with various committees and review panels. A list of these reviews in chronological order and other action relevant to the proposed SPEAR injector is given below:

1) March 11, 1986 : SLAC reviews injector proposal and in a preliminary statement agrees with technical plan, cost and schedule.

2) Stanford University administration authorized SSRL to submit a proposal for the SPEAR injector in the form of a Schedule 44
3) April 15, 1986 : DOE/Headquarters review of SSRL's FY1988 Budget Call including SEP II and Injector Proposal
4) April 25, 1986 : Formal submission of Schedule 44 to DOE
5) May 14, 1986 : SSRL users organization executive committee discussed injector proposal and stated in its report to the SSRL director "..support first priority for a new injector system....
6) May 27, 1986 : SLAC concludes its review of injector proposal
7) May 28, 1986 : Director's Review of the whole SEP II proposal by outside 12 member committee chaired by Marvin Weber of LLNL. The report states "Of the various proposal elements, the 3 GeV SPEAR injector and the 12-m PEP undulator beam line were rated at the top or near-top by all panelists."
8) June 9, 1986 : SSRL Science Policy Board reviewed, among other SSRL plans, the injector proposal and supported it.
9) June 26, 1986 : DOE validation Review at DOE headquarters chaired by Mr.Ramsey (DOE). Submission of conceptual design report.
10) February 1987 : The SPEAR injector has been included in the President's budget for FY'1988 at $13.5 M over three years.
11) February 24, 1987 : Status report of injector project during annual DOE review of the SEP-I project at SSRL
12) March 13, 1987 : Submit new CDR and bottoms-up cost estimate.
13) March 25, 1987 : SSRL program review at DOE headquarters

14) April 21, 1987 : DOE program review
15) August 13, 1987 : DOE Construction Review
16) September 14, 1987 : Technical Review

1.4 R & D Effort for this Injector

The design of the SPEAR injector synchrotron is based on well known and well tested techniques as developed over more than 30 years. No Research and Development is, therefore, required. The project schedule, however, has been adjusted to allow the fabrication of engineering models for some of the major components like magnets and a vacuum chamber to verify the technical solution before a large number of these components are fabricated.

DESCRIPTION

2 General Description of Injector and Parameters

2.1 Performance Goals

The specifications of the injection system were determined to achieve the following objectives:

> The system must provide an electron beam to SPEAR at a maximum energy of at least 3.0 GeV.
>
> It must be an independent system that does not interfere with the operation of any other facility or experiment not associated with SPEAR.
>
> The actual SPEAR filling time should be less than 5 minutes to achieve a circulating current of 100 ma.
>
> The operation of the injector synchrotron should be reliable, easy to operate and of low maintenance so as to allow the integration of the injector operation with the SPEAR operation.

The dedicated SPEAR injector system consists of a short linear accelerator with a beam energy of at least 100 MeV as a preinjector, a 3 GeV slow cycling synchrotron and a beam transport line feeding the particles into the existing SPEAR injection lines. In the first stage the injector is limited to electrons. If positrons should be desired later, a positron option discussed below could be exercised. The "additional cost" is obvious. The energy of the synchrotron has been chosen to match the usual operating energy of SPEAR for synchrotron light users and the injector therefore is a full energy injector allowing maximum use of the synchrotron light source. With a circumference of about 100 m it is possible to place the synchrotron just next to the SPEAR storage ring (Figure 2). At this location the high costs of tunnel construction can be avoided by constructing above-ground radiation shielding as for the SPEAR ring itself.

The preinjector linac is a slow cycling linac which can produce a string of S-band bunches in a single linac pulse. These bunches are stored around the booster synchrotron and then accelerated to the storage ring energy by slowly ramping the booster magnets to higher fields. At the final energy the bunches then are transferred from the booster to the desired buckets in the storage ring.

The total filling time for SPEAR to a circulating current of 100 ma is expected to take less than 5 minutes, assuming a storage efficiency of only 25%. This filling time is very short and is also compatible with our separate effort to increase the current capability of SPEAR to 150 or even 200 ma. Should it ever become necessary to use positrons, additional equipment must be installed. This positron option requires the extension of the electron linac to say 200 to 300 MeV, the addition of a positron converter, a positron focusing system and a 200 to 300 MeV positron linac. The need to use positrons in SPEAR for synchrotron light production has not been positively established yet. Therefore, we propose to construct only an electron injector at this time to minimize costs and construction time.

After acceleration of the electrons to the operating energy of the storage ring the bunches are transferred to the storage ring. At this point the question must be asked if it would be possible to inject, say, every five minutes so as to keep the storage ring current constant. Since this would be desirable, further studies are in order to demonstrate this feasibility. There is no fundamental problem from the injector point of view. In the storage ring, however, the already stored beam would be affected by the pulsed fields of the injection kickers which might be incompatible with experimentation. The scheme might work if the experiments can be interrupted for, say, 5 to 10 seconds every 5 to 10 minutes. In any case, having a dedicated injector, such schemes can be tried out and used if desirable.

2.2 General Design Concept of the Injector

The booster magnet lattice and ring dimensions are shown in Figure 3. The lattice is based on a simple FODO arrangement of the magnets with 18 equal FODO cells forming the total ring. A total of two bending-magnet-free FODO cells provide the space for injection and ejection components, a radio frequency cavity and other minor ring components. Additional space for ring components is provided in the two arc cells adjacent to the straight sections. To minimize the occurrence of synchro-betatron instabilities the dispersion function is chosen to vanish in the straight sections. This is accomplished by using a so-called dispersion suppressor lattice employing different bending angles in the last four bending magnets at the end of the arcs as shown in Figure 3.

Some general parameters of the injection system are compiled in Table 1.

Table 1

General Parameters of the Injection System

Design Energy	3.0	GeV
Circumference	100.445	m
Particles	electrons	
Cycling Rate	2	Hz
Intensity	$1.0 * 10^{11}$	e-/sec
Number of Bunches	≤ 8	
Preinjector	linac	
Linac Frequency	2856	MHz
Energy of preinjector	≥ 100	MeV
Storage Ring Filling Rate (for 25% filling efficiency)	≥ 20.0	mamp/min

The preinjector linac system is designed to cycle at up to 10 pps which is sufficient for all injection modes considered. Each linac pulse consists of one or more equidistant S-band bunches. These bunches are stored in the booster synchrotron and then accelerated to the storage ring energy

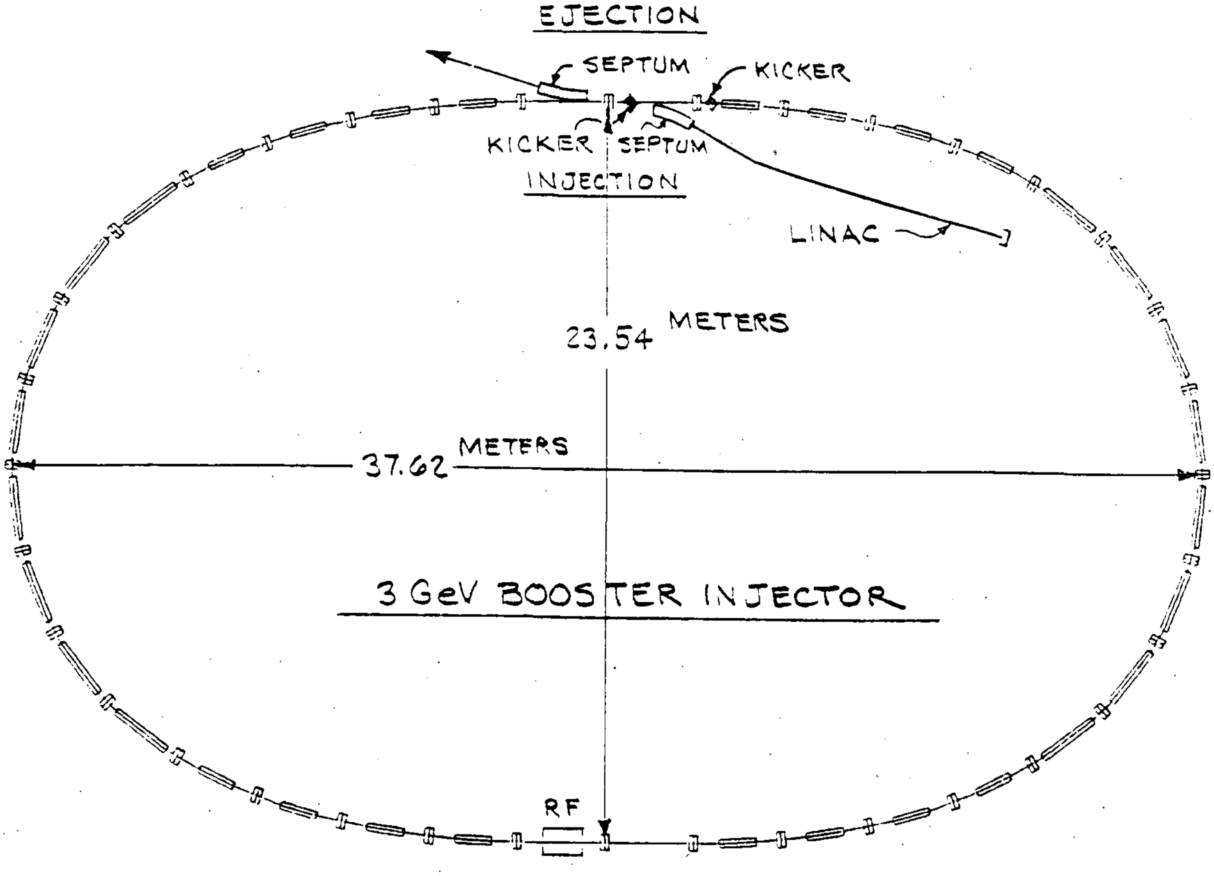

Fig. 3: SPEAR Injector Lattice

by ramping the booster magnets to higher fields. At the final energy the bunches are then transferred from the booster to the desired buckets in the storage ring.

The electrons are generated from a special gun which is designed to deliver a high peak beam current thus avoiding the need for an elaborate prebunching and bunching section in the linac. The linac will consist of standard S-band accelerating structures of the SLAC type. The linac sections will be fed by pulsed S-band klystrons to produce a total beam energy of at least 100 MeV.

For a slow cycling rate of only 2.0 Hz in the synchrotron the total filling time to accumulate a circulating current of 100 ma in the storage ring is expected to be less than 5 minute assuming a particle transfer efficiency of only 25%. During operation in top on mode, when only part of the full beam current needs to be accumulated, the filling times are still shorter. This filling time is very short even if the storage ring current is increased to 200 ma or more since with time the injection efficiency is expected to increase with increased operational experience and understanding of the accelerators.

2.3 Injection Process

The acceleration cycle starts with the injection at 100 MeV of one or more S-band bunches from the preinjector linac after which the magnetic fields of the booster are raised to the energy of the storage ring. At that point the beam is ejected from the booster and transferred to the storage ring. Subsequently the booster magnet current is reduced again to the preinjection value. The actual acceleration time takes about 0.25 seconds for a cycling rate of 2 Hz. Although the damping time at injection is more than 20 seconds long it is quickly reduced as the beam energy is increased and during the short acceleration time to 3.0 GeV the beam has gone through several damping times. At the end of the acceleration cycle the beam parameters therefore are fully determined by the synchrotron radiation in the booster synchrotron and not anymore by the preinjector beam characteristics. This is particular important for positron injection into the storage ring as mentioned previously.

DESIGN

3 Conceptual Design of the Injector System

Basically the design of a synchrotron is similar to that of a storage ring, however, with much relaxed requirements.

For the design of a booster synchrotron a very simple lattice can be employed and special design efforts can be directed toward ease of operation and high reliability. After some special attention during commissioning, a synchrotron must eventually operate without the constant presence of an operator.

3.1 Lattice Design and Beam Characteristics

The design of the synchrotron in this proposal makes use of a simple FODO lattice which has been used for most synchrotrons constructed so far and has proven to be very reliable in its performance. The whole ring consists of 18 separated function FODO cells of which 8 are regular cells, 8 cells have shortened bending magnets to provide automatic matching of the dispersion function into a dispersion free section, and 2 cells are totally free of bending magnets, providing the space needed for injection and ejection components, the RF-system and other machine components (Figure 3). The actual ring lattice deviates slightly from a fully regular FODO aray. In the bending magnet free sections the central quadrupole has been shifted toward one side to accommodate the installation of the RF cavity. The results in a small assymmetry of the lattice functions which, however, does not result in a degradation of performance due to the insensitivity of the design to any kind of errors.

The detailed structure and geometrical dimensions of the synchrotron are compiled in Table 2 :

Table 2

Geometry of the Synchrotron

Circumference (m)	100.34
Diameter (m) long x short	37.647 x 23.587

The lattice structure for one quarter of the ring starting at the arc symmetry point of Figure 3 is given symbolically by:

```
QDH D0  SD  D0  B   D1  QFH QFH D0  SF  D0  B   D1  QDH
QDH D0  SD  D0  B   D1  QFH QFH D0  SF  D0  B   D1  QDH
QDH D5  SD  D6  B1  D6  D5  QFH QFH D5  SF  D6  B1  D6  D5  QDH
QDH D6  D6  B2  D5  D5  D5  QFH QFH D4  D6  B2  D5  D5  QDH
QDH D2B QFH
QFH D2A QDH
QDH D5  D5  B2  D6  D6  DR  QFH QFH D5  D5  B2  D6  D6  QDH
QDH D5  D6  B1  D6  D5  QFH QFH D5  SF  D6  B1  D6  D5  QDH
QDH D0  SD  D0  B   D1  QFH QFH D0  SF  D0  B   D1  QDH
QDH D0  SD  D0  B   D1  QFH QFH D0  SF  D0  B   D1  QDH
```

The parameters of these lattice elements are:

DRIFT:	D0	D1	D2A	D2B	D3
length (m)	0.125	0.25	2.00	3.00	0.75
	D5	D6			
	0.15	0.5			
BEND MAGNET:	B	B1	B2		
length (m)	2.000	1.200	1.200		
bending radius (m)	7.63944	7.63944	11.45916		
HALF QUADRUPOLES:	QFH	QDH			
length (m)	0.1436	0.1436			
SEXTUPOLES:*	SF	SD			
length (m)	0.08	0.08			

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* In the lattice structure the sextupoles are treated as thin lens elements.

All regular FODO cells are 5.574 m long. To minimize the number of magnet power supplies only two quadrupole families are required in this lattice for focusing and control of the operating tunes. All bending magnets are powered by one single power supply. For chromaticity control, two families of sextupoles are sufficient. Finally a set of vertical and horizontal orbit correctors are placed around the ring to allow the control and correction of orbit distortions. In Figure 4 and 5 the betatron and dispersion functions are shown for one quarter of the ring and some relevant lattice parameters are compiled in Table 3. The dispersion function was chosen to vanish in the straight sections for ease of injection and, particularly in the RF section, in order to minimize synchro-betatron oscillations and instabilities.

Table 3

Lattice Parameters

Lattice Type	FODO
Magnet Structure	separated function
Cell Length (m)	5.5744
Total Number of FODO cells	18
Max. Value of Betatron Functions(x/y) (m)	13.0 / 15.4
Max. value of Dispersion Function(m)	1.51
Tunes (x/y)	5.25 / 3.17
Momentum Compaction Factor	0.05404
Natural Chromaticities (x/y)	-6.38 /-5.09
Beam Emittance (mm * mrad) @ 3.0 GeV	0.478
Beam Energy Spread (%)	0.092
Beam Emittance (mm * mrad)	$0.053 * E^2(GeV^2)$
Beam Energy Spread	$0.000305 * E(GeV)$

The chromatic aberrations after chromaticity corrections are very small. The energy acceptance is at least 2.5% (Figure 6) based on lattice considerations only and not considering RF limitations. All chromatic and geometric aberrations are very small as is to be expected for such a lattice.

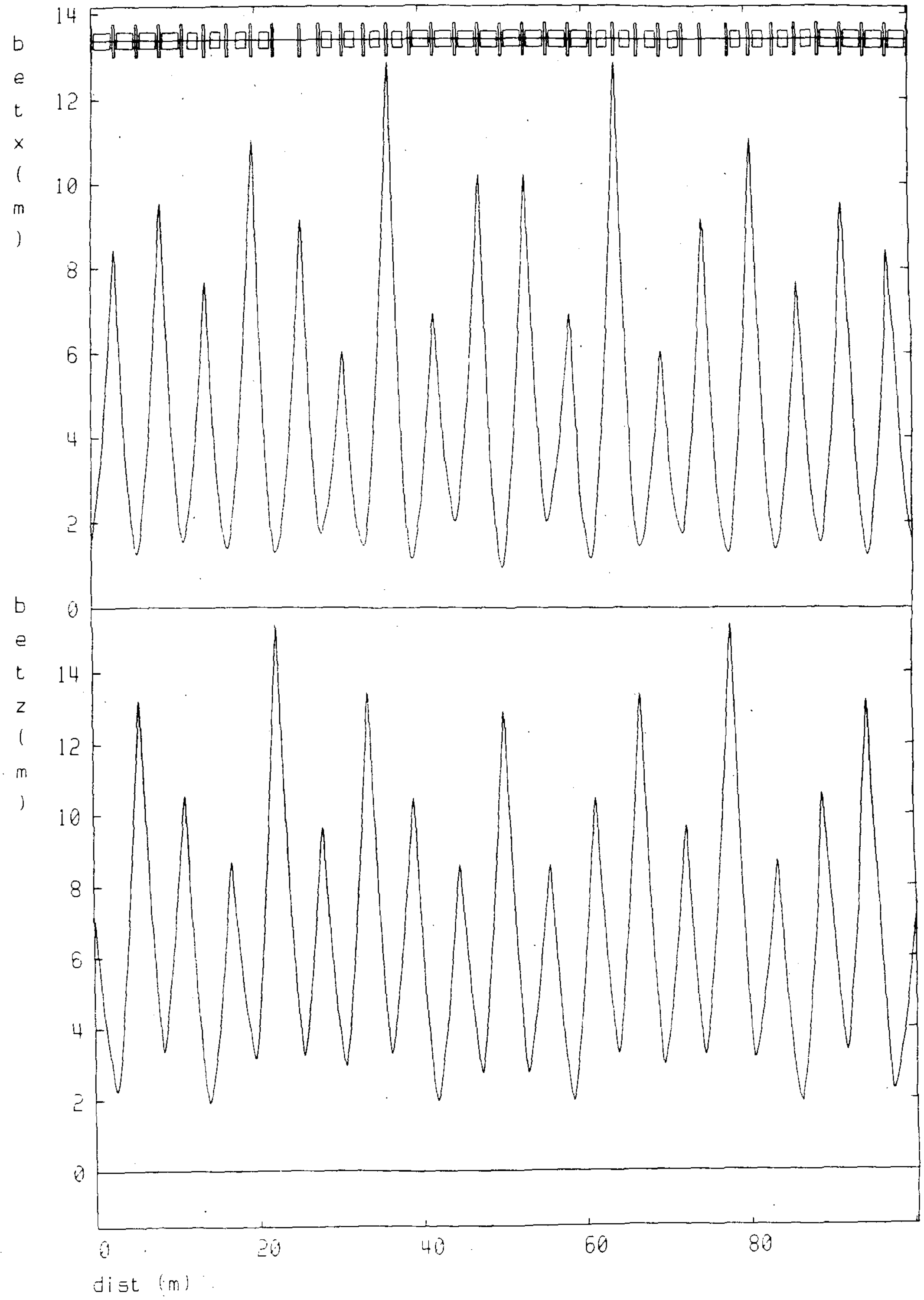


Fig. 4: Betatron Function

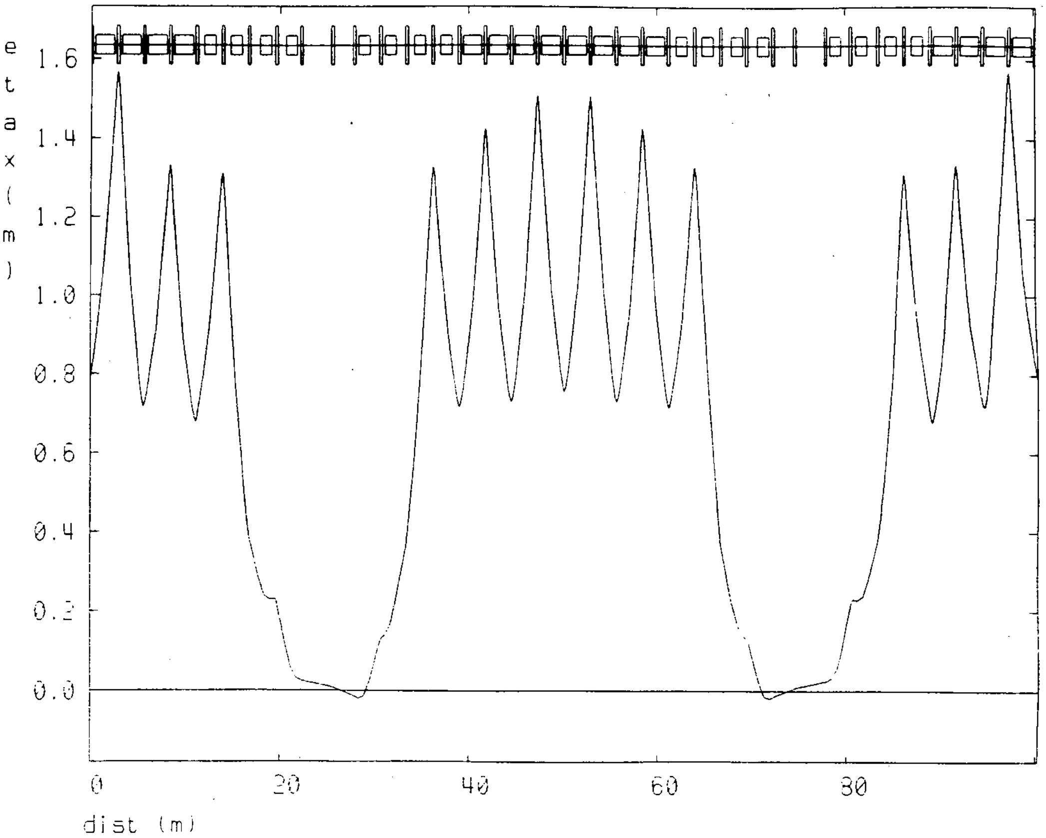
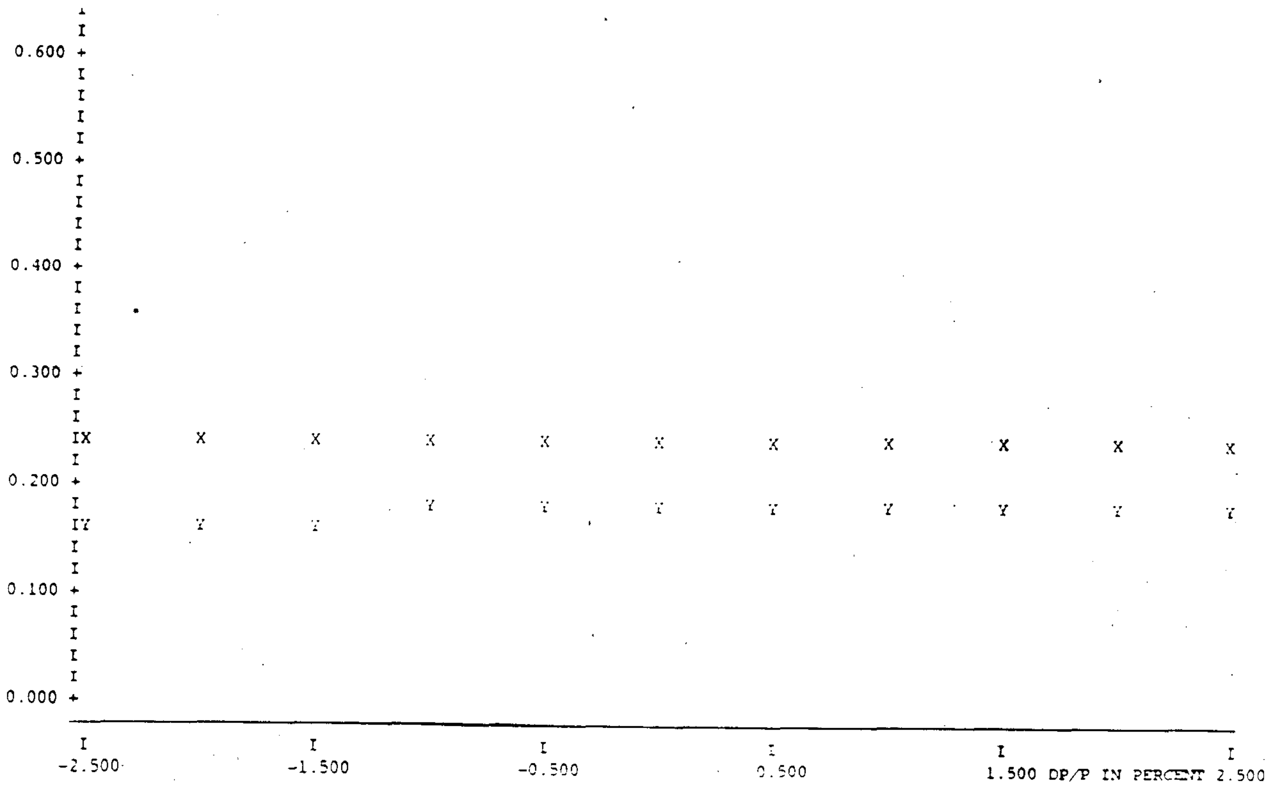


Fig. 5: Dispersion Function

As a result of these weak chromatic and geometric aberrations the dynamic aperture (Figure 7) is much larger than the physical aperture of the vacuum enclosure and provides, therefore, a large margin for unforseen errors.

For ease of injection and specifically in preparation for possible positron injection at a later date a rather large vacuum chamber cross section has been chosen. In Figure 8 the beam stay clear region (BSC) is shown both for the horizontal and vertical plane. The BSC is the maximum cross section a beam may have before particles get lost on the physical or dynamic aperture, whichever is smaller.

The minimum physical aperture or beam stay clear, as shown in Figure 8, is based on the assumption that eventually it will be desired to accelerate positrons injected at 250 MeV. This requires an acceptance in the



NUEX	0.2456	0.2456	0.2456	0.2456	0.2456	0.2455	0.2453	0.2450	0.2446	0.2441	0.2434
NUEY	0.1662	0.1684	0.1698	0.1706	0.1710	0.1711	0.1710	0.1708	0.1707	0.1707	0.1708

Fig. 6: Tune Variation with Energy

storage ring of at least 18 mm*mrad horizontally and 10 mm*mrad vertically. During acceleration the beam reaches the equilibrium beam size as determined by the quantum excitation due to synchrotron radiation and radiation damping. The particle distribution becomes a gaussian distribution and scales linearly with the energy. The beam size is defined as one standard deviation of the gaussian distribution. The vacuum chamber aperture must accommodate at least 5 units of the standard beam size in addition to an allowance for orbit distortions to retain a useful beam lifetime. In this design the beam sizes are smaller than the aperture up to 3.50 GeV. In more detail the beam sizes under various assumptions (see Table 4) have been calculated and have been used to determine the BSC. Extreme beam sizes as required for positron injection or for a higher end energy of 3.5 GeV

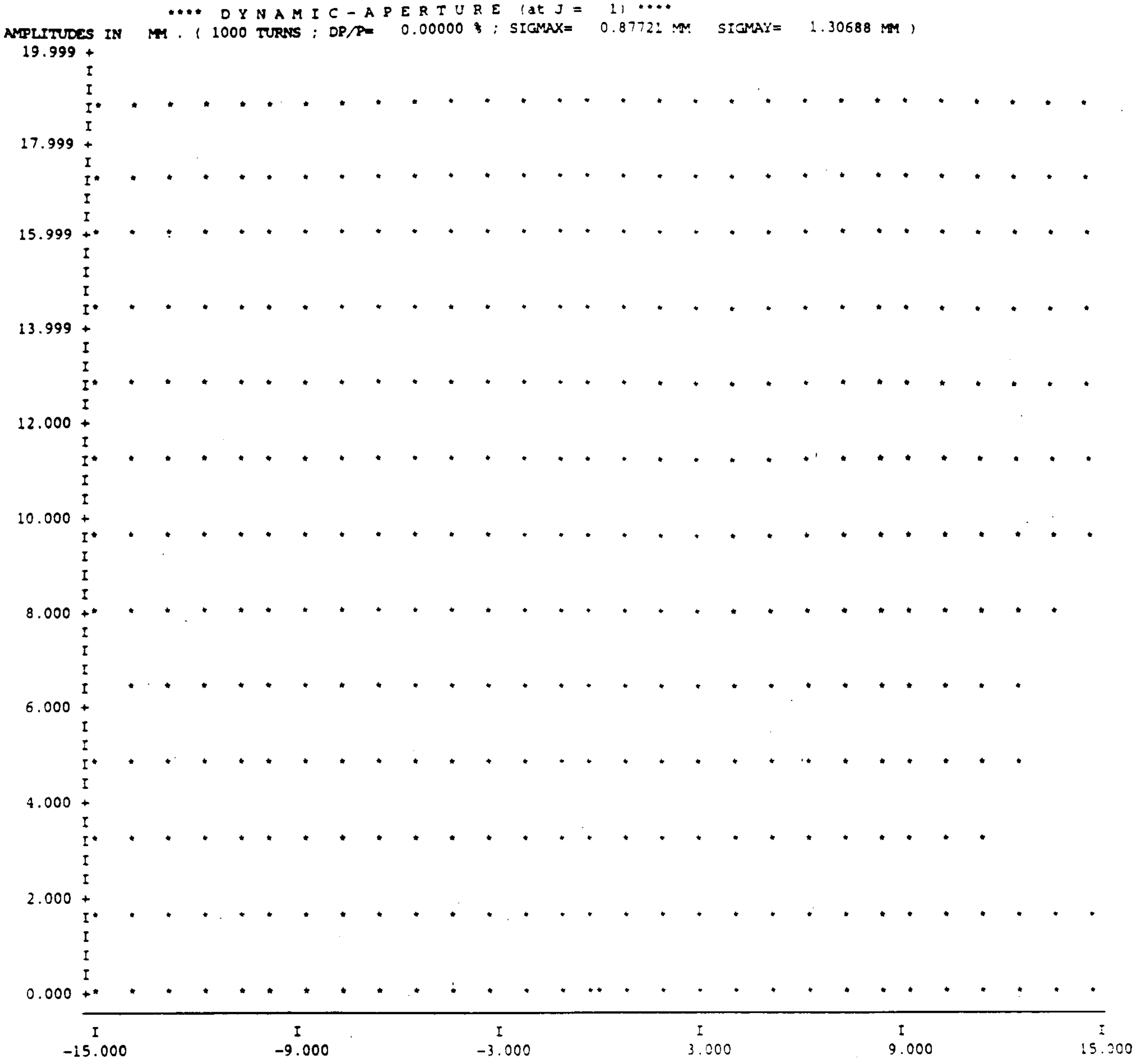


Fig. 7: Dynamic Aperture

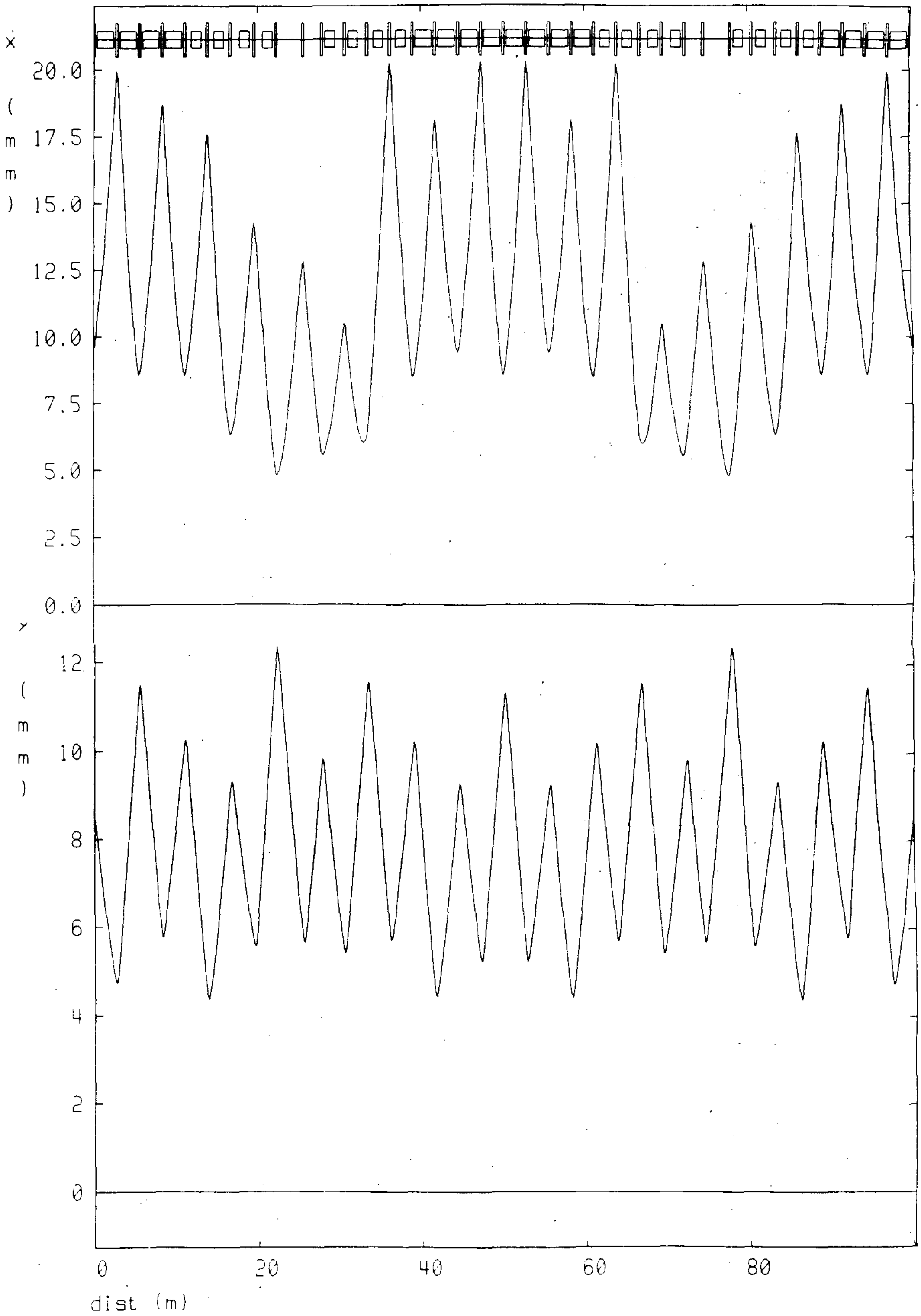


Fig. 8: Beam Stay Clear in the Booster Injector

have been used to determine the required vacuum chamber aperture.

Table 4

Beam Size under Different Conditions

Electron Beam:	
at injection (100 MeV):	
Beam Emittance (both planes)	0.10 mm * mrad
Energy Spread	1.0%
Max. Beam Width	14.5 mm
Max. Beam Height (quad)	1.1 mm
at a higher energy of 3.0 GeV:	
Beam Emittance (1 σ)	0.65 mm * mrad
Max. Beam Width ($\pm 5\sigma$)	32.3 mm
Max. Beam Height (quad)	22.4 mm
Max. Beam Height (bend)	20.4 mm
Positron Beam:	
at injection (250 MeV):	
Beam Emittance (Horizontal)	18.0 mm * mrad
Beam Emittance (Vertical)	10.0 mm * mrad
Energy Spread	1.0%
Max. Beam Width	40.5 mm
Max. Beam Height (quad)	24.8 mm
Max. Beam Height (bend)	22.7 mm
at the higher energy of 3.50 GeV:	same as electrons because of damping

The maximum beam width for any beam considered is about 40 mm and the maximum beam height in the quadrupoles and in the bending magnets is less than 25 mm. A circular free aperture of 50 mm diameter for the quadrupole vacuum chamber and a clear height of the bending magnet vacuum chambers of 32 mm is, therefore, assumed for this ring, leaving 10 mm in both planes for orbit distortions. The dynamic aperture has been determined to be much larger than the physical aperture in both planes.

A summary of general parameters of the ring and the lattice functions are given in Table 5:

Table 5

Synchrotron Parameter

Energy	3.0	GeV
Circumference	100.339	m
Cycling Rate	2	Hz
Revolution		
Frequency	2987.79	kHz
Time	335	nsec
Lattice	FODO	
Cell length	5.5744	m
Beam Emittance	.478	mm * mrad
Energy Spread	0.092	%
Energy Loss/Turn	0.896	MeV
Tunes: ν_x	5.250	
ν_y	3.170	
Lattice Functions		
β_{xmax}	13.0	m
β_{ymax}	15.4	m
η_{xmax}	1.57	m
Natural Chromaticity		
ξ_x	-6.38	
ξ_y	-5.09	
RF frequency	358.53	MHz
Harmonic number	120	
Momentum Comp. Factor	0.05404	
Transverse damping time	2.241	msec
Vacuum chamber aperture		
x:(quad) (diameter)	50	mm
y:(bend) (height)	32	mm
Acceptance x:	69.4	mm * mrad
y:	22.4	mm * mrad

A more detailed compilation of the injector lattice and its parameters is attached in Appendix A.

3.2 Technical Components

The design of the technical components for the booster synchrotron follows well established technology. No major R & D is necessary for any of the components. Synchrotrons have been constructed for many years and no special new feature is required to use a synchrotron as an injector.

The main technical components of the injector system are the preinjector linac, the magnet, RF and vacuum systems, beam control and monitoring, injection and ejection and utilities.

3.2.1 Preaccelerator Linac

The preaccelerator for injection into the booster synchrotron consists of a linac composed of three accelerating sections of the SLAC type and a microwave gun similar to those used in microtrons to produce the electron beam. The three accelerating sections are each powered by their own klystron. For the initial start up it is assumed that SLAC surplus klystrons at a power rating of at least 20 MW can be secured for this purpose. These SLAC klystrons become available due to the replacement of older klystrons with new 60 MW klystrons as part of the SLC project.

3.2.1.1 Microwave Gun

The electrons are generated in the microwave gun from a LaB_6 cathode which, when heated to 1600 K^0, can deliver current densities in excess of 100 A/cm^2. This type of gun is used in microtrons as well as in linear accelerators.[Ref] The cathode reaches directly into the high field of a microwave cavity where the electrons are quickly accelerated to relativistic energies.

[Ref] G.A. Westenkow et. al., Laser and Particle Beams, Vol. 2, part 2, (1984), pp.233.
S.V. Benson et. al., Proc. of 1985 FEL Conference Granlibakken.

After focusing and energy definition the beam is injected into the linear accelerator sections for acceleration to more than 100 MeV. This type of a gun can produce an instantaneous electron current of more than 10 amp. The advantage of such a gun compared to the often used thermionic gun is that the electrons are accelerated by an RF field to relativistic energies in the very short distance of about 3 cm, the length of one S-band cavity. This fast acceleration efficiently overcomes the electrical space charge forces which cause a significant increase in beam emittance and beam size. For optimum injection efficiency into the booster we plan to take advantage of this greatly reduced beam blow up in a microwave gun. One further advantage of this type of gun is that no other equipment, like prebuncher or buncher section, is required in the linac since the beam is automatically bunched through the field of the microwave gun cavity. This greatly reduces the complexity of the preinjector and allows easy operation.

With a peak current of 10 amp from the microwave gun we expect a population of $4.2\ 10^8$ electrons in each 2 mm S-band bunch. For a much longer bunch length the energy spread in the beam becomes large. Some of the gun parameters are summarized in Table 6:

Table 6

Microwave Gun Parameter

Gun Cavity Frequency (MHz)	2856
Particle Energy (keV)	> 500
Cathode Peak Current (amp)	≥ 10.0
Bunch Length (mm)	2.0
Particles/S-Band Bunch	$4.2\ 10^8$
Particles per 3 S-Band Bunches	$12.5\ 10^8$

3.2.1.2 Momentum Filter

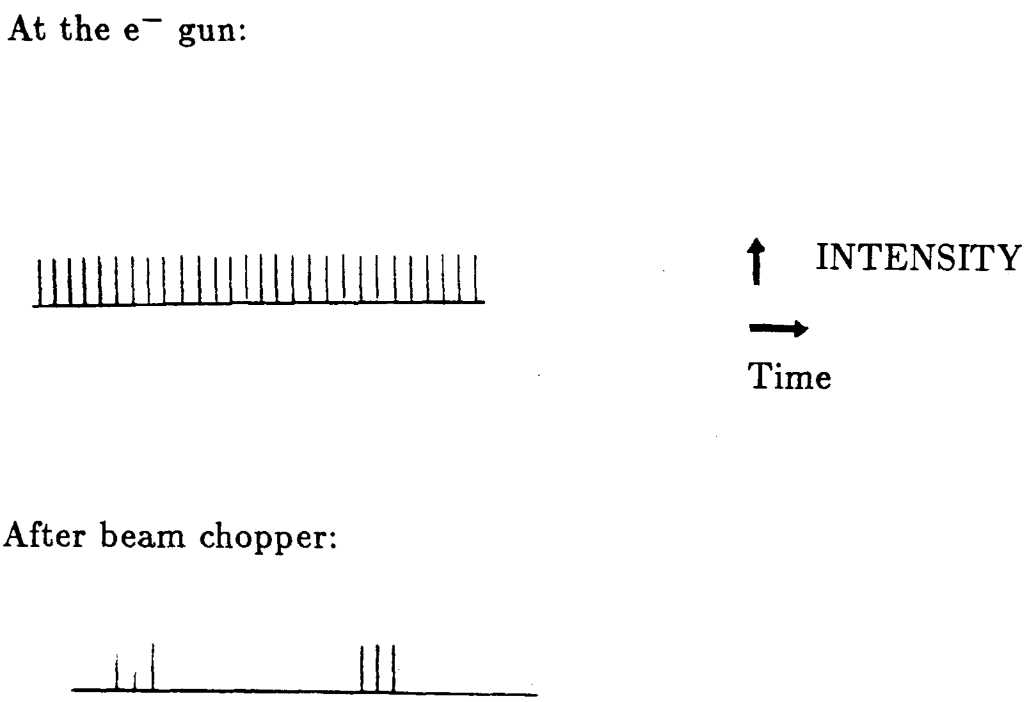
The energy spread of the electron beam from the microwave gun is very large due to the varying RF field in the cavity. A magnetic momentum filter will be used to eliminate all particles with energies outside the acceptable energy bin. This momentum filter makes use of the momentum dispersion caused by the deflecting field of a dipole field. Placement of a slitted absorber at the position of maximum momentum dispersion allows selection of a narrow momentum bin from the beam for further acceleration.

3.2.1.3 Beam Chopper

Without any further devices a long string of electron bunches, separated by the linac RF wavelength of 10 cm, would enter the linac sections (see Figure 9). Not all of these bunches can be accepted by the booster synchrotron or by the storage ring. To reduce the level of radiation caused by these partially accelerated and eventually lost particles, it is prudent to eliminate these particle bunches at very low energies. This is performed by a device called a chopper located between the momentum filter and the linear accelerator. The string of S-band bunches emerging from the microwave gun will be modified by the chopper in such a way as to fit special requirements of the booster synchrotron and storage ring.

Since the booster RF frequency is much lower than the linac RF frequency, it is possible to accept three or even more consecutive linac bunches into one booster RF bucket, where they eventually merge into one bunch by radiation damping. Therefore, a chopper composed of a fast deflector with a slit will be used to generate, from the continuous stream of S-band bunches, a particle beam made up of a string of equidistant triplet bunches. Each triplet consists of three consecutive S-band bunches and the distance between the triplets is equal to the desired bunch distance in the booster synchrotron (Figure 9).

The conceptual layout of the chopper is shown in Figure 10. Here a DC magnetic field deflects the beam from the gun into an absorber. Superimposed is an electrical pulsed field which deflects the beam against the magnetic field toward the slit and allows the beam, during a short time period, to emerge through the slit to be accelerated in the linac. This way a string of S-band triplets can be produced for multibunch injection into


At the e$^-$ gun:

After beam chopper:

Fig. 9: Bunch Patterns in the Injection System

the booster and SPEAR.

While this multibunch mode of operation is the prevailing mode of operation in SPEAR, there are occasions when a single or few bunches are desired.

For timing experiments it is desirable to make use of the very short storage ring bunch to excite atomic or molecular states with an extremely short burst of photons. To observe the decay of these states a "long" radiation free time must follow. In the extreme case only one bunch would be filled in the SPEAR storage ring providing a radiation free time equal to one full revolution time. For this case also only one bunch is being accelerated per accelerating cycle in the booster. This booster bunch consists of 3 linac

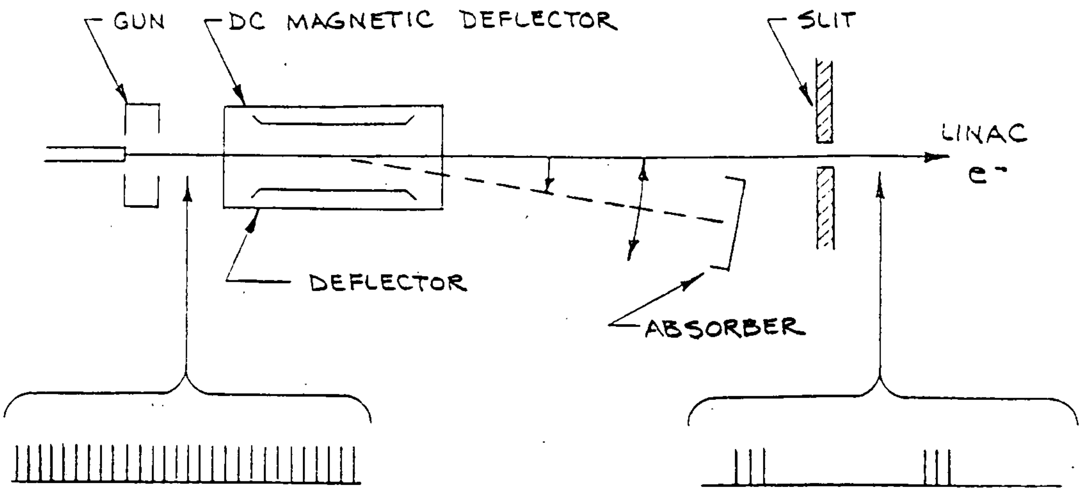


Fig. 10: Beam Chopper System

buckets and therefore 12.5 10^8 electrons are accelerated per cycle giving an injection rate for a single bunch in the SPEAR storage ring of at least 5.0 mamp/min assuming a 25% overall transfer efficiency and a booster cycle rate of 2.0 Hz. Since the single bunch current in the storage ring will not be larger than 10 to 20 mamp because of instabilities or Touschek lifetime limitations, a single bunch filling time of less than five minute can be expected from this injector.

When many bunches are desired in the storage ring, strings of bunches can be accelerated and transferred to the storage ring in a single pulse. In this mode of operation the fastest storage ring filling rate of more than 50 ma/min can be achieved assuming eight bunches to be accelerated per booster cycle and a 25% injection efficiency into the storage ring. This will also be the most efficient mode of operation for beam cleaning the vacuum chamber in SPEAR to achieve long beam lifetime.

For further planning we will assume the preinjector beam characteristics as compiled in Table 7:

Table 7

Preinjector Beam Parameter

Energy from Preinjector (MeV)	≥ 100
Number of Booster Bunches	8
Number of Particles per Pulse	10^{10}
Pulse Repetition Rate (Hz)	2
Total Energy Spread at full Linac Energy	0.010
Normalized Beam Emittance ($\epsilon\,\gamma$)	
Horizontal (m)	$20\ 10^{-6}$
Vertical (m)	$10\ 10^{-6}$
Beam Emittance	
Horizontal (m)	$0.085\ 10^{-6}$
Vertical (m)	$0.043\ 10^{-6}$

With these preinjector beam parameters we expect to achieve the SPEAR injection parameters as summarized in Table 8. For the multi bunch made we assume 8 bunches to be accelerated in the booster while only a single bunch in accelerated for single bunch mode in SPEAR.

Table 8

SPEAR Injection Parameters

Storage Ring Bunch Mode	Single Bunch	Multi Bunch
Storage Ring Beam Current (ma)	20.0	100.0
Circumference (m)	234.0	234.0
Total Number of Particles (10^8)	975	4875
Injection Efficiency (%)	25.0	25.0
Number of Booster Cycles needed	312	195
Booster Cycles per Second	2	2
Storage Ring Filling Time (min)	2.6	1.6
Storage Ring Filling Rate (ma/min)	7.7	61

3.2.1.4 Linear Accelerator

For the acceleration of the electrons coming from the gun to high energies, three 10 foot accelerating sections of the SLAC type will be used. The energy gain per linear accelerator sections is determined by the RF power from the klystrons and is given by:

$$E_0(MeV) = 10 * (P(MW))^{1/2} = 54.8\,MeV$$

This energy gain per section can be obtained straightforward without relying on any RF-pulse compression scheme like the SLED scheme. In the three accelerating sections, therefore, a total "no load" energy of about 164.4 MeV can be reached if three 30 MW klystrons are used. In reality, however, this "no load" energy gain is reduced by beam loading leading actually to a somewhat lower beam energy of at least 100 MeV depending on the intensity of the beam accelerated. The performance of the booster synchrotron basically improves with increasing injection energy from the preinjector. However, this dependence is rather weak and the additional complexity of a SLED'ed accelerating scheme is not advisable. From a technical view point a SLED'ed mode of operation is also not desirable since it would not allow the acceleration of a long string of bunches.

The proposed mode of operation of the linac sections is straight forward and most components are expected to be, and perform similar to those used at the Stanford Linear Accelerator.

Some of the main parameters of the linear accelerator are compiled in Table 9.

Because of the low repetition rate of no more than 10 Hz, the RF power requirements for the linac are very modest. This allows a reduced cost and complexity compared to the SLAC high power klystron modulators required for high pulse repetition rates. In Table 10 the klystron and modulator specifications are summarized.

Table 9

Linac Parameter

Accelerating Sections	three
Length/Section (m)	3.0
Frequency (MHz)	2856
Type	constant impedance
RF Filling time (sec)	$0.75 * 10^{-6}$
Klystron/Modulators	three
Pulse Power (MW)	≥ 30.0
Pulse Length (sec)	1.5 to $2 * 10^{-6}$
Pulse Rep. Rate (Hz)	≤ 10
Preinjector Energy (MeV) (no load)	164.4
Pulse Length (nsec)	> 330

Table 10

SLAC Klystron Parameter

Klystron Peak Output Power	35	MW
Frequency	2856	MHz
Peak Beam Voltage	265	kV
Peak Beam Current	286	A
Peak Beam Power	75.8	MW
Repetition Rate	10	Hz
RF Pulse Length (max)	1.5	μ – sec
Modulator Pulse Length (max)	3.35	μ – sec
Klystron Efficiency	47	%
AC Power	3.32	kW
Focusing Magnet	permanent	
Cathode Type	oxide	

3.2.1.5 Beam Transport to the Booster Synchrotron

A beam transport system will guide the electron beam from the preinjector linac to the booster synchrotron where it will be injected “on axis” through a full aperture kicker magnet. Bending and focusing magnets will match the beam to the optical parameters of the synchrotron at the injection point. A septum magnet close to the synchrotron will align the beam direction so as to let the incoming beam cross the booster beam orbit in the middle of the full-aperture kicker magnet. This kicker magnet then will be turned on for not more than one revolution time of 330 nsec to align the injected beam exactly with the ideal booster beam orbit. The kicker magnet must be turned off before the time the first particles, arrive again at the kicker location after one turn in the booster,

Along the transport line beam characteristics like beam intensity, energy and energy spread will be measured and controlled. For this purpose intensity monitors are installed in the transport line. A dispersive section of the transport line will make measurements and determinations of the exact beam energy and energy spread. This analyzing station will be helpful in setting up the preinjector beam while the SPEAR storage ring is used for experiments. For this purpose a downstream bending magnet will be turned off to guide the beam into a separate beam dump. A Faraday cup in front of this beam dump can be inserted into the beam for a precise beam intensity measurement.

Beam position monitors and scintillators with TV cameras will be installed to observe the beam position and quality. Orthogonal steering magnets at the end of the transport line are designed to allow the independent adjustment of the beam position and angle at the injection point.

Because of the low beam energy rather small magnets are required and the power supplies therefore are chosen to be the same as those for the beam steering magnets in the booster.

3.2.2 Magnet System

For the booster synchrotron the magnets must be constructed in such a way as to minimize the occurrence of eddy currents during energy ramping. Therefore, the magnet cores are constructed from laminations of low carbon steel stock. All magnets can be split in the horizontal midplane to allow the installation of the vacuum chamber.

The aperture of the magnets is determined by the larger of both the injected beams size and the beam size at high energies plus an additional allowance required for orbit distortion in the vacuum chamber. The space required for the beam, called the "beam stay clear" region or BSC, is shown in Figure 8 and was determined mostly by the size of a positron beam during injection at 250 MeV. The requirements for the electron beam both at injection and at 3 GeV are smaller.

The magnetic field properties are modeled with the help of a computer program MAGNET which has been used extensively for the design of synchrotron and storage ring magnets at CERN and elsewhere. Finally the magnet quality will be determined by magnetic measurement which allows expansion of the magnetic field into the fundamental field and the higher harmonics. The magnet pole shapes will be determined such as not to cause beam instability by higher harmonic field errors.

Special trim coils and orbit correction magnets in connection with beam position monitors will be used to control the beam orbit during acceleration.

Three different types of magnets are required for the booster synchrotron:

- bending magnets to bend the electrons onto circular paths,
- quadrupole magnets to hold the particles in the vicinity of the ideal design orbit within the vacuum chamber, and,
- sextupole magnets to correct chromatic aberrations which can cause beam instabilities.

The construction of these magnets as well as the alignment follows well established procedure since the simplicity of the lattice does not require high construction and alignment tolerances.

3.2.2.1 Bending Magnets

The main bending magnet system consists of a total of 32 H type magnets. All bending magnets have the same cross section as shown in Figure 11 but have different lengths and field strengths to accomplish the matching of the dispersion funtion to zero in the straight sections. The main parameters of the bending magnets are compiled in Tables 11 and 12 :

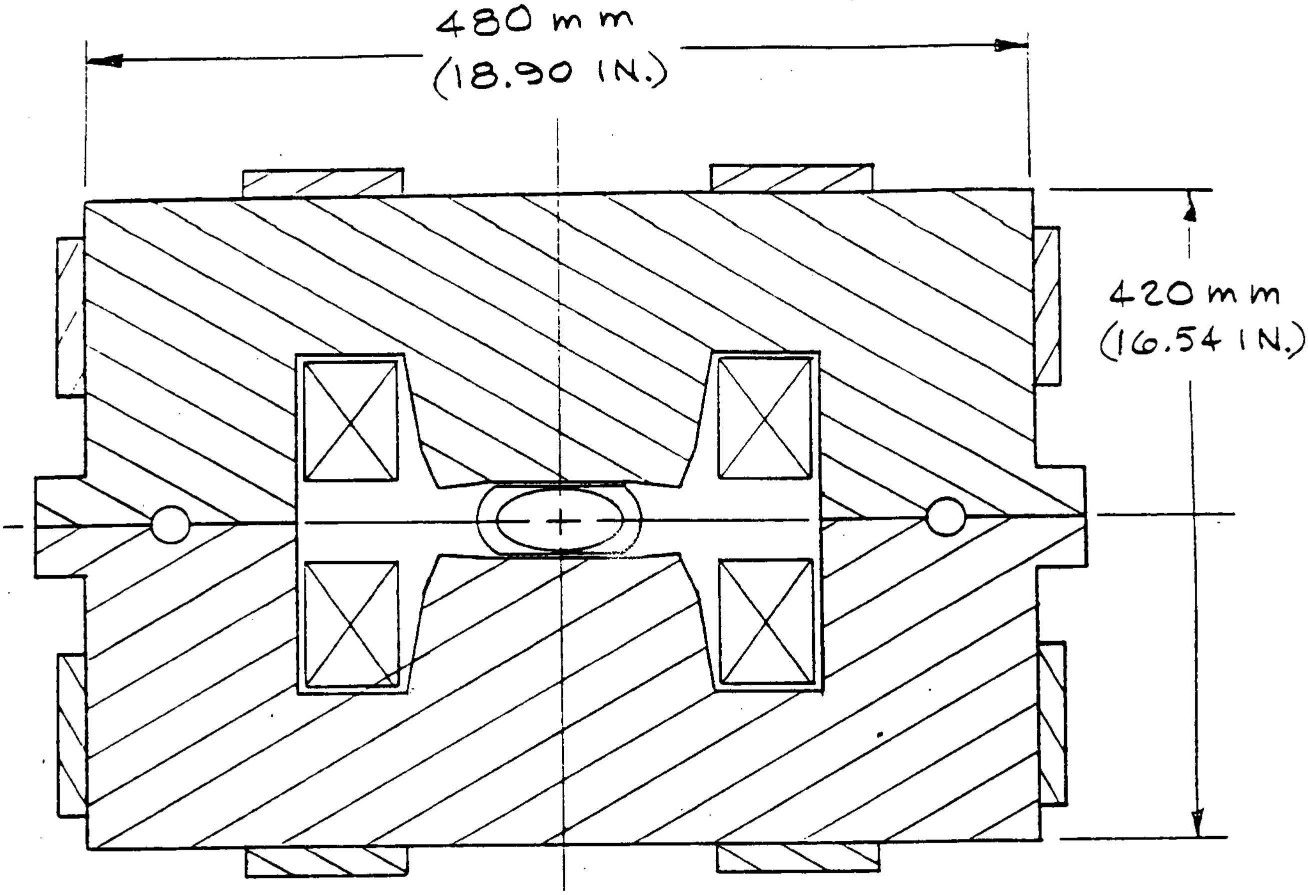


Fig. 11: Bending Magnet Cross Section

Table 11

Bending Magnet Types

Magnet Designation	B	B1	B2
Length (m)	2.000	1.200	1.200
Field Strength at 3.0 GeV (kGauss)	13.09	13.09	8.72
Field Strength at Injection (Gauss)	524	524	349
Max. Strength (kGauss)	>15.70	>15.70	> 10.47
Number of Magnets	16	8	8

The sagitta of the beam orbit in the longer magnets is quite significant at 65 mm. If one would build a straight magnet the pole width would have to be 65 mm wider and the total magnet would be 130 mm wider than required for the beam alone. To minimize the width of the magnets it is planned to "bend" the magnet by splitting the iron core into straight blocks with wedge-shaped spacers in between (Figure 12). Still the whole magnet would be powered by two long excitation coils.

The maximum required strength of all magnets is 13.09 kGauss for 3.0 GeV leaving a comfortable margin for higher energy operation if so desired. The main specifications for the bending magnets are compiled in the Table 12:

Table 12

Bending Magnet Specification

Magnet Name in Lattice	B	B1	B2
Straight Magnetic Length (mm)	2000.000	1200.000	1200.000
Bending Radius (mm)	7639.437	7639.437	11459.160
Bending Angle (radian)	0.314	0.173	0.141
Bending Angle (degrees)	15.0	9.0	6.0
Gap Height (mm)	34.0	34.0	34.0
Sagitta (mm)	65.4	23.5	15.7
Length of Iron (mm)	1966.0	1166.0	1166.0
Weight of Iron (kg)	2439.0	1466.0	1446.0
Weight of Copper in both Coils	333.0	207.7	138.4
Elect.Power at 3.0 GeV (kW)	13.9	8.9	6.0

The magnetic field properties are shown in Figure 13 where the calculated field errors are plotted for the midplane of the magnet aperture for a field strength of 13 kGauss. No serious saturation effects occur as can be seen from Figure 14 where the permeability is plotted across one quarter of the otherwise symmetric magnet for 13 kGauss. The calculated excitation curve is shown in Figure 15. Obviously below 13 kGauss there is little saturation.

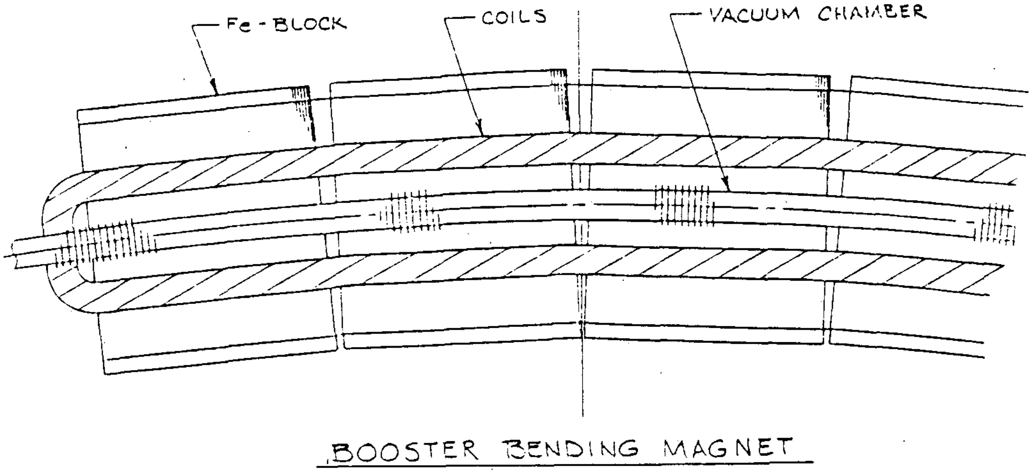


Fig. 12: Construction of the Bending Magnets

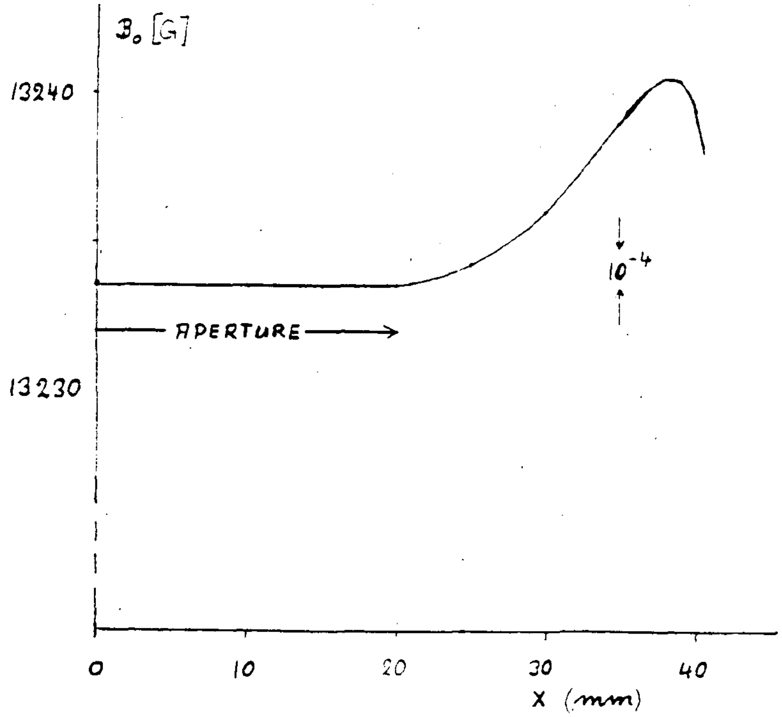


Fig. 13: Bending Magnet Field Errors

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PERMEABILITY MAP.

DISTANCE BETWEEN COLUMNS =   20.00MM (=  2 TIMES H)
DISTANCE BETWEEN ROWS    =   10.00MM (=  1 TIMES H)


2000 2810 3160 2840 2114 1472 1292 1304 1426 1769 2503 3160 2899 2000
2155 2996 3160 2815 2101 1465 1289 1303 1423 1757 2484 3160 3151 2226
2589 3160 3160 2754 2061 1444 1280 1298 1414 1723 2426 3158 3160 2917
3159 3160 3160 2670 1995 1408 1266 1291 1399 1662 2332 2971 3160 3160
3160 3160 3098 2563 1906 1357 1248 1282 1380 1577 2210 2710 3132 3160
3160 3160 2866 2429 1799 1282 1224 1272 1354 1446 1990 2404 2595 2677
3089 2905 2636 2274 1680 1195 1198 1261 1327 1299 1745 1963 2011 2017
2660 2568 2372 2060 1524 1055 1166 1249 1291 1031 1338 1280 1212 1189
2331 2262 2075 1772 1374  937 1138 1240 1264  844  899  863  855  854
1984 1901 1720 1445 1088  701 1098 1229 1223  439  612  656  680  688
1694 1634 1481 1210  825    0    0    0    0    0  427  512  554  566
1550 1514 1431 1305 1131    0    0    0    0    0  458  478  494  499
1491 1469 1419 1347 1268    0    0    0    0    0  422  440  453  458
1483 1469 1439 1399 1356    0    0    0    0    0  399  419  432  437
1505 1497 1480 1458 1433    0    0    0    0    0  390  414  430  435
1546 1542 1535 1525 1514    0    0    0    0    0  404  431  449  456
1596 1597 1599 1603 1608    0    0    0    0    0  441  471  495  504
1648 1653 1665 1688 1724    0    0    0    0    0  223  453  557  592
1692 1700 1722 1763 1834    0    0    0    0    0   65  426  761  835
1719 1728 1753 1799 1892    0    0    0    0    0    0    0    0    0
1728 1735 1753 1771 1752    0    0    0    0    0    0    0    0    0
```

Fig. 14: Saturation of the Bending Magnet at 13 kGauss

Eight bending magnets require a smaller field strength than the rest of the magnets. For these magnets a modified coil with fewer turns is considered such that the correct field strength is obtained for all magnets while being powered in series by one and the same power supply.

All magnets are equipped with trim coils to provide orbit correction capabilities. The maximum strength of the trim coils will be specified as to allow the correction of any reasonable orbit distortion expected in the synchrotron.

The total peak power for the bending magnets is expected to be about 341 kW while the average power is 33% of that.

The bending magnet system parameters for the injector are tabulated in Table 13.

Table 13

Beam Energy	3.0	GeV
Total Weight of Iron	62170	kg
Total Weight of Copper	5633	kg
Total el. Power @ 3 GeV	341	kW
Electrical Current	328	amp

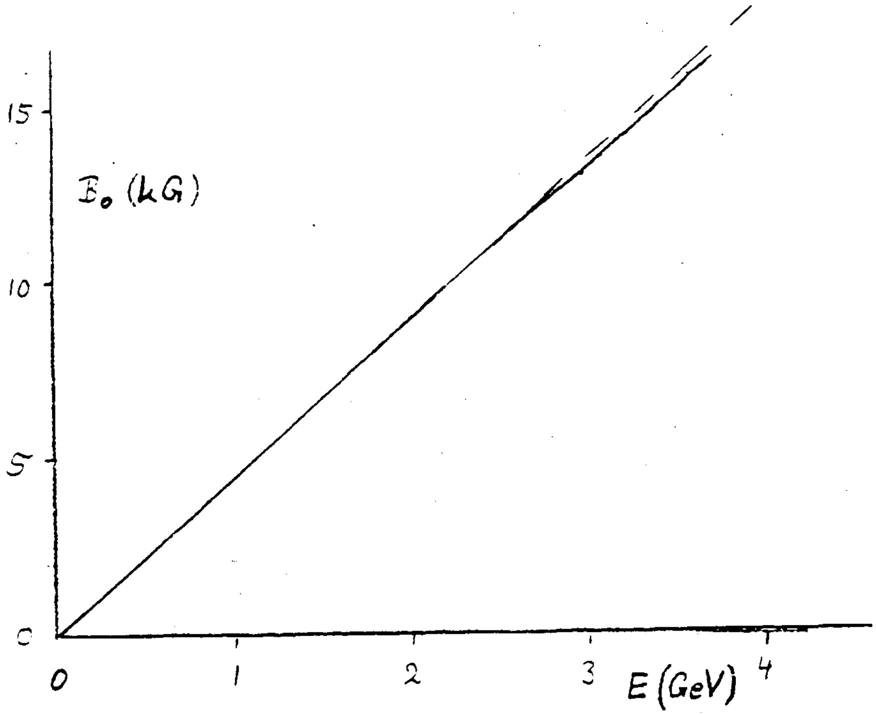

Fig. 15: Excitation Curve for the Bending Magnets

3.2.2.2 Quadrupole and Sextupole Magnets

The focusing is performed by 32 identical quadrupoles, each 0.287 m long, and the chromatic correction requires 2422 sextupoles with a magnetic length of 0.10 m each. To avoid eddy currents these magnets also are constructed from low carbon steel laminations like the bending magnets.

There are two families of quadrupoles, the QF's and the QD's, each forming one electrical circuit. The strength of the two quadrupole types are:

$$\begin{aligned} QF : k &= -1.9766\,m^{-2} && \text{or for } 3.0GeV : && g = 1.9780 kGauss/cm \\ QD : k &= 1.4478\,m^{-2} && \text{or for } 3.0GeV : && g = 1.4488 kGauss/cm \end{aligned}$$

The specifications of the quadrupoles and sextupoles are compiled in Table 14:

Table 14

Quadrupole and Sextupole Specification

Magnet Name in Lattice	QF/QD	SF/SD
Magnet Designation	30Q287	30S100
Magnetic Length (mm)	287.2	100.0
Bore Radius (mm)	30.0	35.0
Maximum Field Gradient (G/cm)	2400.0	
Field Gradient at 3.0 GeV	$\leq$ 1978.0	
Pole Tip Field at 3.0 GeV (Gauss)	$\leq$ 5934.0	450.0
Total Current/Coil (amp*turns)	$\leq$ 7085	358
Length of Iron Block (mm)	257.2	100
Weight of Iron (kg)	338.3	
Weight of Copper (kg)	59.0	
Number of Magnets	36	22
Power per Magnet at 3.0 GeV (kW)	$\leq$ 4.60	
Construction	laminated	laminated

All quadrupoles and sextupoles have the same cross sections as shown in Figure 16 and Figure 20.

The calculated saturation characteristics for the quadrupoles are shown in Figure 17 where the permeability is plotted across the magnet for a field gradient of 2.0 kGauss/cm.

The magnetic field properties for the quadrupoles are shown in Figure 18 where the calculated gradient errors are plotted for the midplane of the quadrupole aperture for a gradient of 2.0 kGauss/cm.

The calculated excitation curve for the quadrupoles is shown in Figure 19. Obviously there is little saturation for beam energies up to 3.0 GeV.

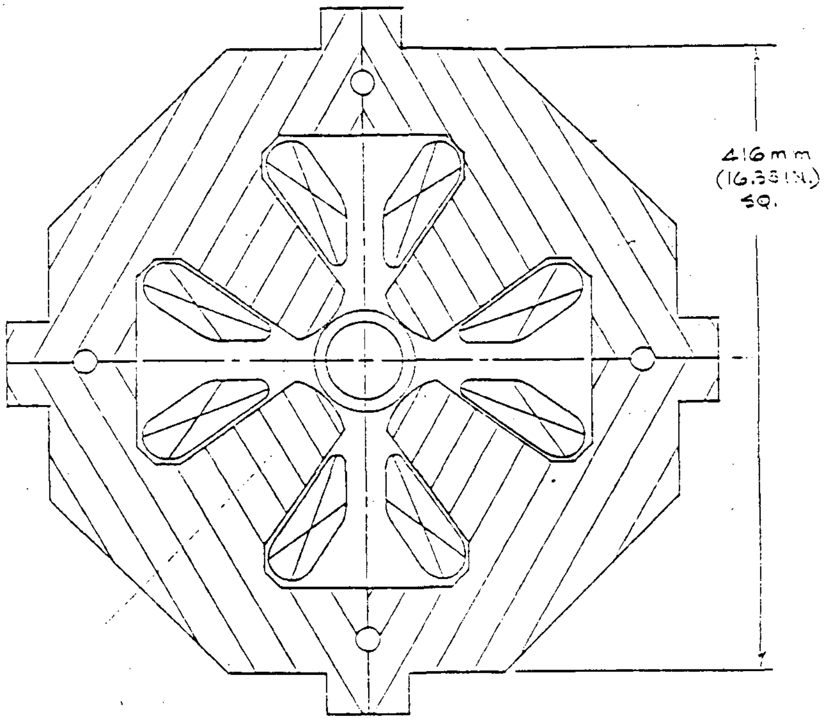

Fig. 16: Quadrupole Cross Section

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PERMEABILITY MAP.

DISTANCE BETWEEN COLUMNS =   10.00MM
DISTANCE BETWEEN ROWS    =    5.00MM

    0    0    0    0    0    0    0    0    0    0    0    0    0    0    0    0    0    0    0
    0    0    0    0    0 2000 2000    0    0    0    0    0    0    0    0    0    0    0    0
    0    0    0    0    0 2000 2002    0    0    0    0    0    0    0    0    0    0    0    0
    0    0    0    0 2099 2041 2063 2166    0    0    0    0    0    0    0    0    0    0    0
    0    0    0    0 2178 2131 2152 2245    0    0    0    0    0    0    0    0    0    0    0
    0    0    0    0 2267 2230 2257 2346 2502    0    0    0    0    0    0    0    0    0    0
    0    0    0 2437 2369 2348 2381 2465 2619    0    0    0    0    0    0    0    0    0    0
    0    0    0 2534 2482 2481 2527 2619 2759 2978    0    0    0    0    0    0    0    0    0
    0    0 2691 2637 2621 2648 2710 2804 2932 3077    0    0    0    0    0    0    0    0    0
    0    0 2758 2751 2783 2851 2931 3018 3078 3078 3078    0    0    0    0    0    0    0    0
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Fig. 17: Saturation Characteristics for the Quadrupoles

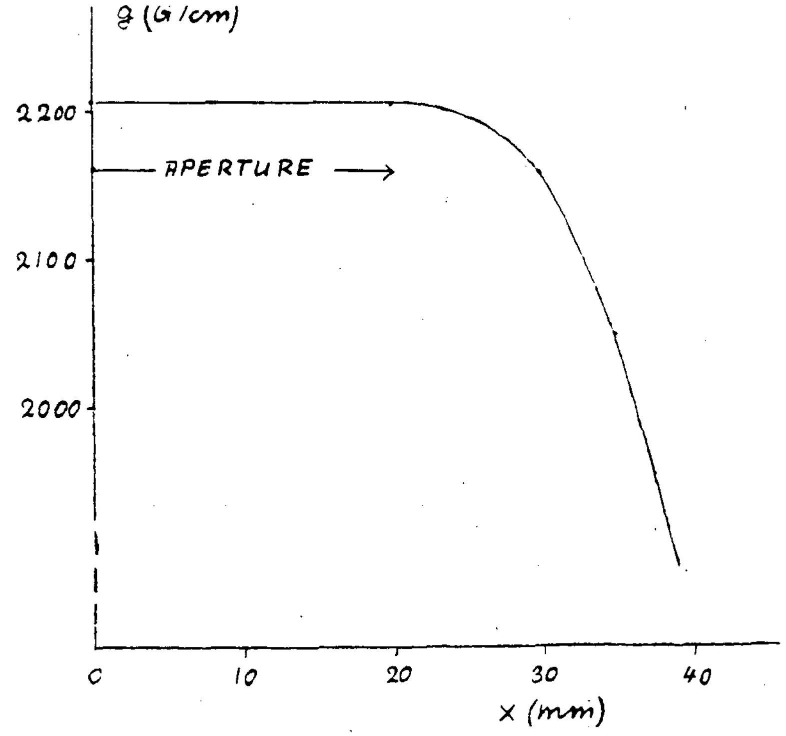

Fig. 18: Quadrupole Gradient Errors

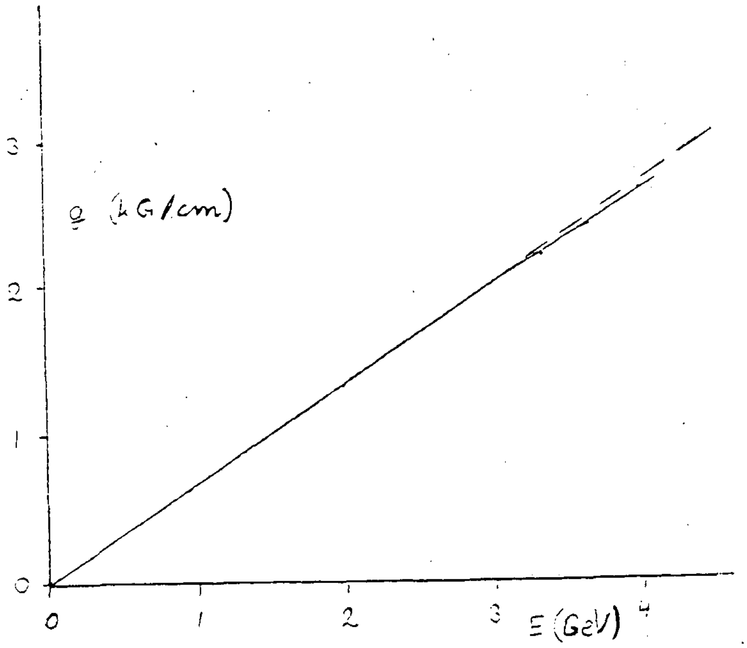

Fig. 19: Excitation Curve for the Quadrupole Magnets

3.2.2.3 Special Magnets

Most magnetic fields used for orbit correction will be generated by trim coils in bending magnets and quadrupoles. They will be powered by independent, DC power supplies With trim coils in time-varying fields, like for the bending and quadrupole magnets, a significant voltage is induced in each trim coil which is too large for the small power supplies. Hence the alternating voltage must be removed from each correction circuit. Following the suggestion by the ESRF group for their booster, we propose to add a special "bucking" magnet in the dipole circuit.[Ref] This will be a separate dipole magnet connected to the main dipole circuit but not part of the ring lattice. Each correction circuit will have an auxiliary winding on the core of this magnet with the number of turns and the polarity chosen such as to

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[Ref] ESRF, Foundation Phase Report, February 1987, Grenoble (France)

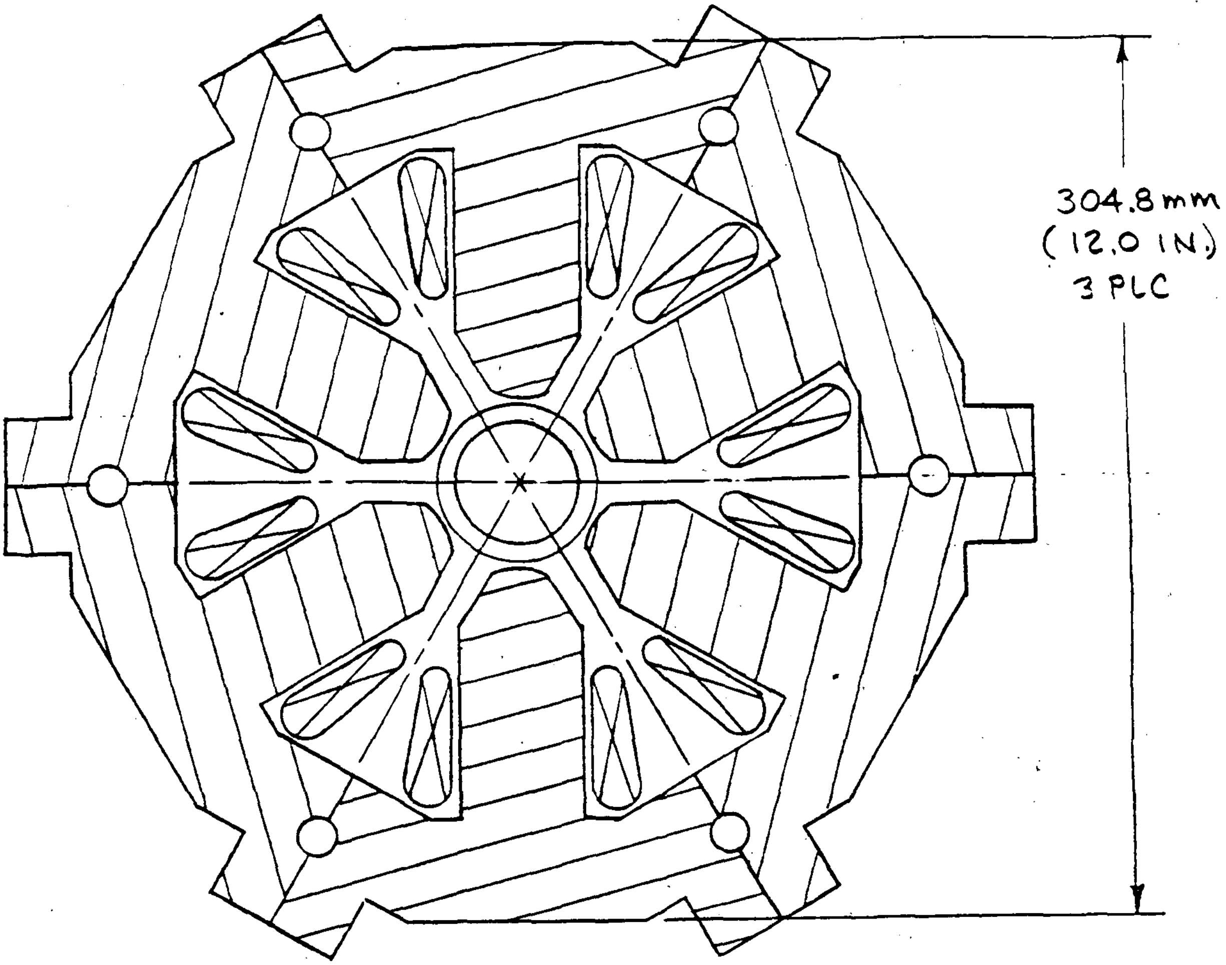


Fig. 20: Sextupole Cross Section

cancel the voltage induced in the main correction winding.

3.2.2.4 Magnet Power Supplies

The power supplies must be designed such as to excite the magnets from the injection energy of 100 MeV to high field levels corresponding to 3.0 GeV operation up to 2 times a second. To accomplish this it is proposed to use a a computer controlled DC power supplies or classical "White" circuits as used in many previously constructed synchrotrons. The latter power circuit consists of a combination of one DC supply and two AC supplies. Together with a choke and two capacitor banks, this "White" circuit provides an oscillating current for the magnets between zero and a maximum value. An internal filter is incorporated to minimize the harmonic content of the output current.

A total of five power supplies will be needed, one for the bending magnets, two for the QF and QD quadrupole circuit and two simple pulsed power supplies for the SF and SD sextupole circuits.

No special AC power supplies are required for orbit control. In a properly designed synchrotron the orbit changes little during the acceleration process. It is, therefore, anticipated that only DC correctors are required, for which standard DC power supplies can be used. Of course, in this case the significant induced voltage from the main bending fields must be compensated in a bucking magnet as outlined above, to use these ordinary DC supplies.

For the proper functioning of the synchrotron it is important that the fields in the bending magnets and the quadrupoles track together. Tracking errors can be caused for example by mechanical variations of the magnet gaps during the magnetic field cycle. It is, therefore, important to construct the magnets so as to produce maximum rigidity. This is a strong argument for designing the bending magnets as H-magnets rather than C-magnets. Another source of tracking errors can come from the power supply characteristics which are different for the bending magnet and quadrupole circuit. If a computer controlled power supply is used each circuit cn be controlled appropriately. In case of the White circuit, the bending magnet circuit will be adjusted to a fixed frequency to minimize the power rating of the invertor to generate only a pure resistive load on the power mains. This will cause the quadrupole circuits to oscillate at a slightly different frequency and, therefore, a phase control servo system will be required to keep all magnets tracking properly. More detailed engineering is required to choose between both types of power supplies to suit best the SPEAR injector requirement and environment.

3.2.3 Acceleration System

To accelerate the electrons from the preinjector energy to the final storage ring operating energy, a 358 MHz RF system will be used. This system makes use of a 5-cell cavity which has been used in SPEAR and has been secured from SLAC surplus. One such cavity is sufficient to accelerate the electrons up to 3 GeV.

If the RF-system were operated just like in a 3 GeV storage ring at a constant RF-voltage level the system would require a RF-power of 150 kW of which about 135 kW are losses in the cavity walls. These losses can be greatly reduced if the RF-voltage is modulated during the accelerating process to the minimum values needed by the particles at any time. This modulation can be easily achieved by control of the klystron drive. At the highest energy of 3 GeV, however, the klystron power must reach a maximum instantaneous power of 150 kW to generate a sufficiently large accelerating voltage in the cavities to overcome the synchrotron radiation losses. This power rating is less than that for the klystrons presently used in SPEAR. To simplify maintenance it is proposed to use the same klystrons as for the SPEAR storage ring although they are, at 500 kW, overrated. The relative small cost difference between a 150 kW and 500 kW klystron makes this decision simple.

The low level electronics and power supplies will be of the same design as for the SPEAR or PEP RF-systems. No new development is necessary.

The choice of the accelerating system is mainly determined by the available surplus accelerating cavity from SPEAR. This cavity operates at a frequency of 358 MHz, has a shunt impedance of 30 MOhm and can absorb in its cooling system an average power of about 100 kWatt. The cavity consists of five cells coupled together in π mode by two slots in the common wall between the cells. The construction material is Aluminum 6061. A layer of Titanium Nitride deposited on the surface of the cavity serves to prohibit field breakdown by multipactoring. A water cooled loop in the center cavity is used to couple the RF power from the klystron into the cavity.

The cavities are equipped with a movable tuner and a sampling loop. The tuner is used to compensate for the thermal expansion of the cavity which causes a change of the resonance frequency. The field amplitudes are monitored by the sampling loop and the signal is compared with a reference signal to set the desired RF Voltage in the cavity. The resulting difference signal is applied to a variable attenuator in the drive line to the klystron. The whole system is similar to the SPEAR or PEP control system and could also be equal to the system used for the storage ring.

The accelerating system of a synchrotron, in addition to providing the accelerating field U_{accel} to raise the electron energy from 120 MeV to 3.0 GeV, also compensates for the loss of energy due to synchrotron radiation U_{rad} and the energy lost due to the excitation of parasitic modes U_{pm}.

The energy balance can be written like:

$$U_{tot} = U_{accel} + U_{rad} + U_{pm},$$

where

$$U_{accel} = (E - E_0) / (T_c * f_{rev})$$

where E = 3.0 GeV, E_0 the linac energy, T_c is the ramping time of the synchrotron and f_{rev} is the particle revolution time in the synchrotron.

For this synchrotron we have at 3 GeV:

$$\begin{aligned} f_{rev} &= 2974kHz \\ T_c &= 0.10sec \\ U_{rad} &= 1MeV \\ U_{accel} &= 10.0keV \\ U_{pm} &= 0.4keV \\ U_{tot} &= 1.01MeV \end{aligned}$$

Here we have assumed that the maximum cycling rate for the synchrotron is 10 Hz.

The parasitic mode parameter for the SPEAR cavity K_{pm} is 1.5 V/pCb and the number of electrons per bunch is at most $2*10^9$ in a maximum of 8 bunches. The parasitic mode loss in the SPEAR cavity, U_{pm}, therefore, is no more than 0.4 keV. The required accelerating voltage, even for a fast cycling booster at 10 pps and the maximum expected beam loading, is negligible compared to the synchrotron radiation losses. The RF power, therefore, is mainly applied to replace the synchrotron radiation energy loss.

The RF parameters of the injector synchrotron are:

Frequency	358	MHz
Harmonic Number	120	
No. of Klystrons	1	
No. of Cavities	1	
Cavity shunt impedance	30.0	MOhm
Max. Cavity Power	130.0	kWatt
Avg. Cavity Power	35.0	kWatt
Max. Cavity Voltage	2.0	MVolt
Max. Beam Power	4.0	kWatt

During each accelerating cycle, the electron energy raises from 120 MeV to 3.0 GeV and the synchrotron radiation energy loss per turn increases from 1 eV to 900 keV. Therefore, to minimize power consumption and to avoid beam instability the RF power will be modulated from 5 kW to 135 kW as shown in Figure 21. This modulation must be split into two regimes: one for energies from 100 MeV to 1.3 GeV and the other for 1.3 GeV to 3 GeV. During the first step, the RF power is kept at about 5 kW which is the minimum stable output power for the klystron. The RF voltage in the cavity is, in this case, 387 kV and provides an energy acceptance of 1.6% at injection and of 0.5% at 1.3 GeV. During the second step the energy acceptance is kept at a minimum 0.5% and the resulting RF power and RF voltage in the cavity are shown in Figure 21 and 22. This kind of modulation of the RF power can be achieved by controlling the drive power to the klystron. Of course more energy acceptance can be obtained should that be desirable for some reason, by raising the RF power up to the maximum level of 100 kW as limited by the cavity cooling capacity.

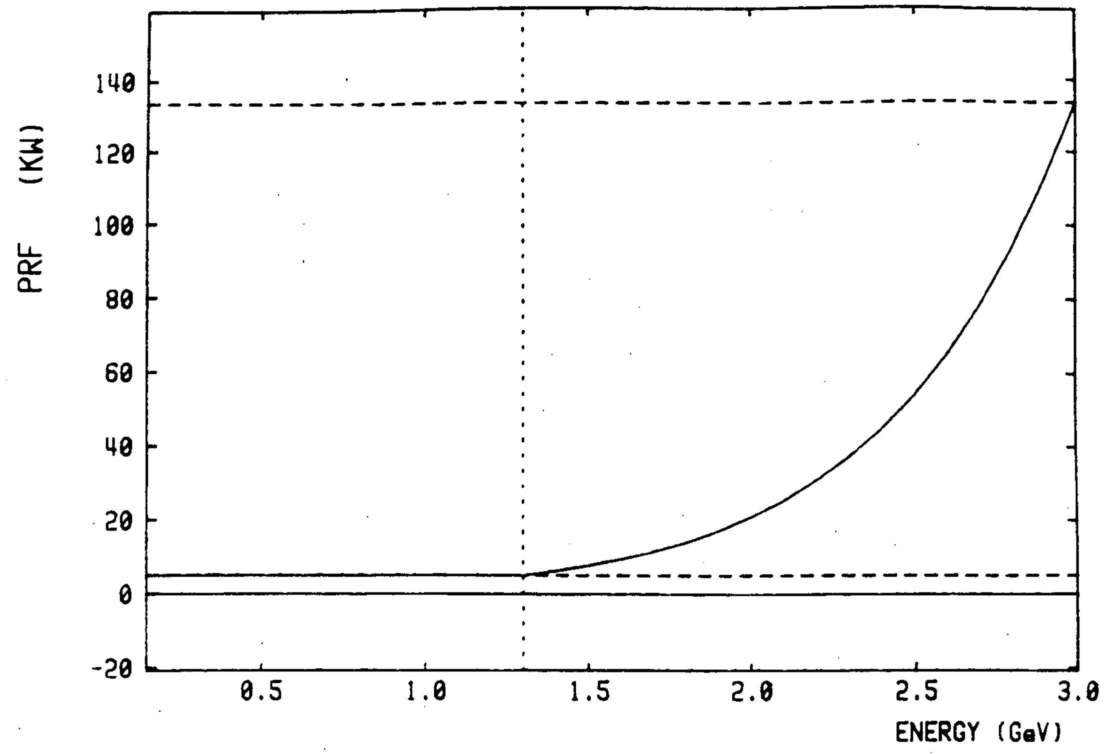


Fig. 21: The Cavity RF Power Variation with Beam Energy

3.2.4 Vacuum System

In a booster synchrotron a special design of the vacuum chamber must be employed. Fortunately, since the particles remain in the synchrotron only a very short time, an operating pressure of 10^{-6} Torr is sufficient and the high fabrication and maintenance costs of an ultra-high vacuum system can be avoided. Also the synchrotron radiation heating of the wall can be shown to be quite negligible due to the low average current and low duty cycle, so no special cooling of the vacuum chamber walls will be required. However, the changing magnetic fields during acceleration will induce eddy currents in the chamber material which can greatly affect the magnetic field quality inside the vacuum chamber. This effect can be avoided by using

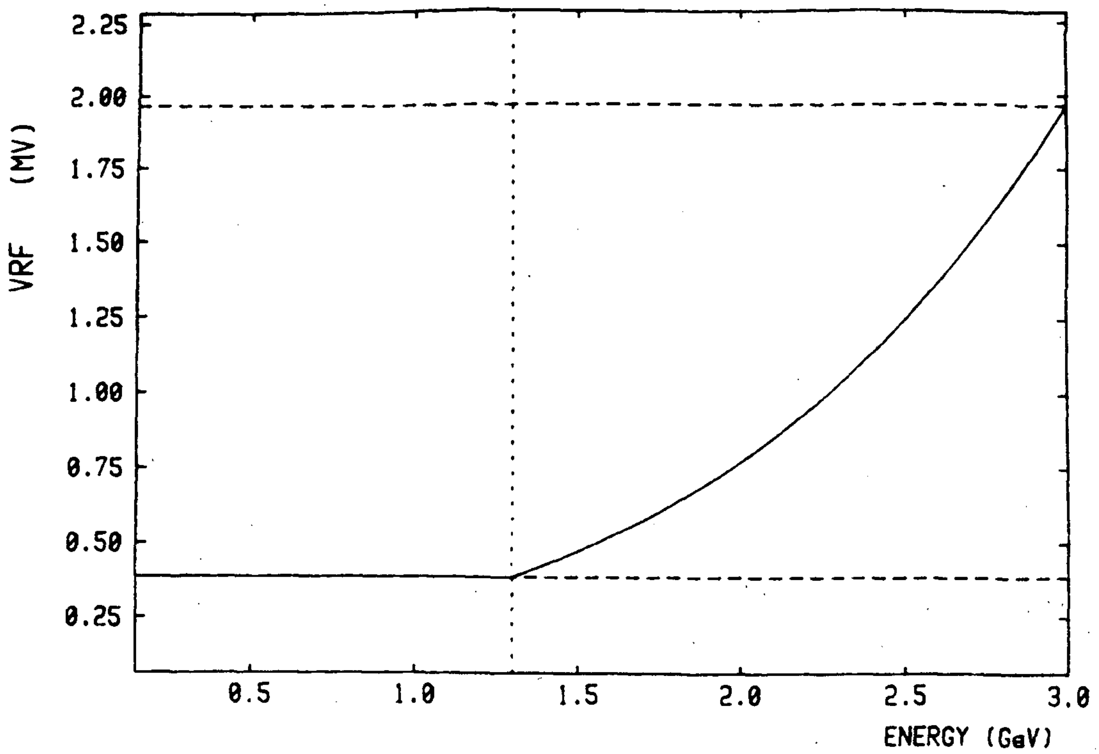


Fig. 22: Variation of the Cavity Voltage with Beam Energy

costly ceramic chambers, or for slow cycling synchrotrons such as proposed here, by using vacuum chambers made of very thin (0.3 mm) stainless steel pipes. In this proposal such a thin walled stainless steel chamber is used. To avoid the collapse of this chambers under atmospheric pressure external stiffening ribs will be attached to the outer surface at periodic longitudinal intervals. The ribs must be designed to fit within the various magnet pole gaps. Such a design has been successfully used at DESY in the recently constructed 12 GeV synchrotron, and allows the booster to be cycled at up to 12 times per second.

The pumping system design is dictated largely by the cross-sectional dimensions required for the vacuum chamber to fit inside the poles of the magnets. In the quadrupoles and sextupoles, a thin-walled round tube of approximately 50 mm diameter appears to be suitable. A number of round tubings can be partially flattened to an an approximately elliptical cross section of dimension 32 mm by 40 mm and used in the bending magnet regions. These dimensions allow the use of external ribs of sufficient thickness to provide the stability against atmospheric pressure within the specified quadrupole and sextupole bore diameters. In the bending magnets the stiffening rips would be only 1 mm in the pole gap but much wider in the horizontal plane (Figure 23).

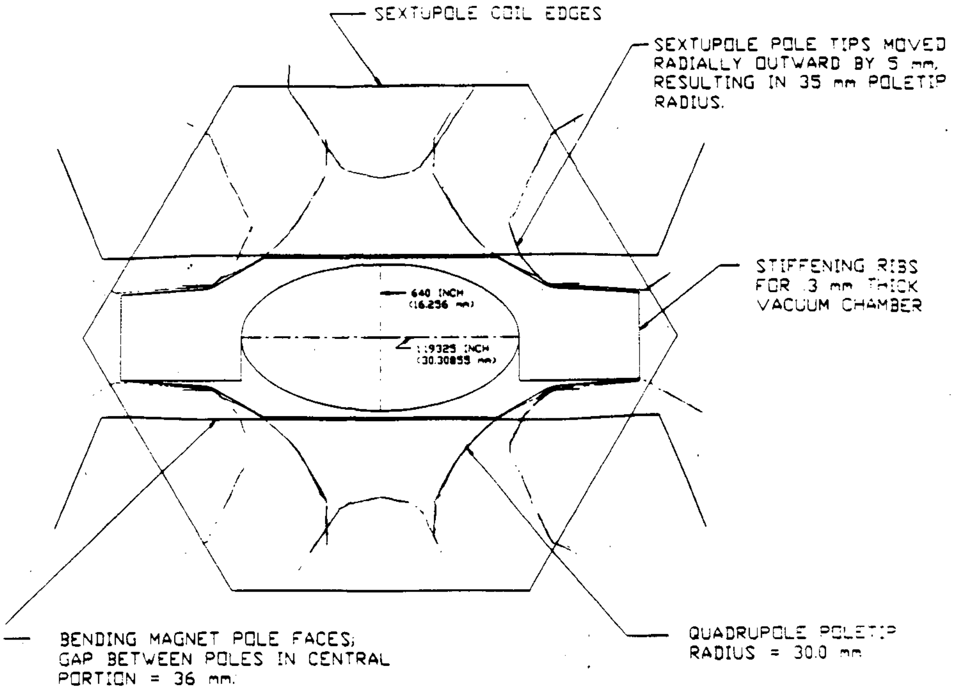


Fig. 23: Vacuum Chamber Cross-section

An analysis has been made of the pressure distribution in a long tube of the above-mentioned dimensions with thermal outgassing rates assumed to be those of clean, degreased but unbaked stainless steel, and ignoring the very small gas desorption due to synchrotron radiation. It shows that an average pressure in the booster ring of about 700 n Torr can be achieved using only lumped ion pumps. In particular one 8 l/sec ion pump for each 2.8 meter long cell in the lattice is sufficient to reach that pressure. No distributed pumps in the bending magnets are required. Thus, for maintaining an adequately low and smooth pressure profile around the ring, 36 ion pumps with a pumping speed of 8 l/sec, approximately equally spaced, will be installed. To minimize cost several ion pumps at a time will be connected to one power supply. A set of vacuum gauges will be used to monitor the pressure around the ring.

To evacuate the ring from atmospheric pressure down to a pressure where ion pumps can safely be turned on, gate valves are used to segment the ring into sectors that can be evacuated separately. A mobile mechanical roughing pump together with liquid-nitrogen-cooled sorption pumps will be connected to the vacuum chamber at the center of each sector. Each sector is then evacuated separately until the ion pumps can be started. When the vacuum pressure reaches a sufficiently low value in all sectors, the gate valves can be opened.

Taking advantage of the highly periodic magnet lattice only one basic type of vacuum chambers are needed to cover all of the ring. Each chamber reaches through one bending magnet, and one quadrupole/sextupole combination. All chambers are joined by conventional 4.5 inch Conflat flanges.

Each quadrupole/sextupole section consists of a straight round steel tubing with simple circular rings on the outside as stiffening ribs where necessary. The repetitive chambers will be connected by a conventional pump-out tee with bellows. A single ion pump and the valve to the roughing system will be attached here. At one end, near the flange, an axi-symmetric beam position monitor (BPM) module will be installed, and at the other end, a short bellows section to accommodate small manufacturing tolerances. A thin ceramic ring will be incorporated at the end of each chamber to avoid induced current circulation in the ring. The layout of the arc vacuum chamber with pumping is shown in Figure 24.

3.2.5 Instrumentation and Controls

The controls of the booster synchrotron components are mostly incorporated into the hardware. The accelerating system, for example, will have an internal feedback system to keep the RF parameters constant at the desired values. During the energy ramping process the quadrupole power supply amplitudes and phases will be controlled by a small computer to assure

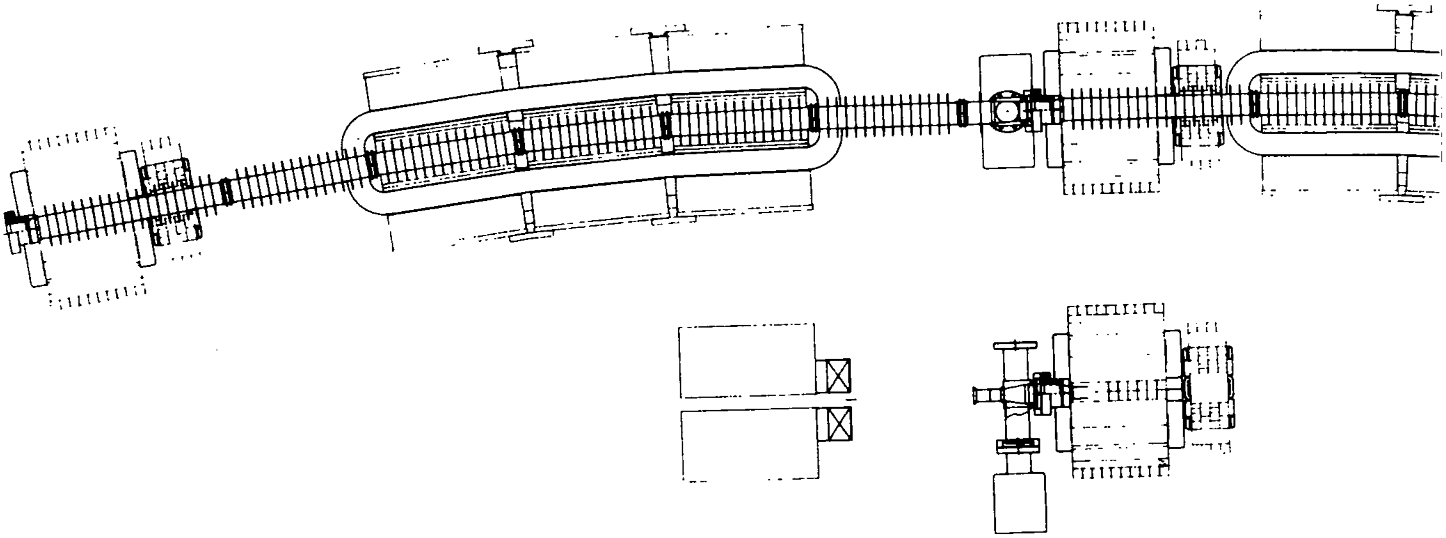


Fig. 24: Arc Vacuum Chamber

proper tracking with the bending magnet current and field. Similarly the beam current or the beam position will be recorded and displayed during acceleration. In this way it is possible to operate the booster synchrotron independent from the storage ring control computer which will be important during initial debugging. A separate control console with a microcomputer will be available to operate the injector independent from the SPEAR control system. On the other hand the booster components are ready to be controlled by any other computer and therefore can be also connected to the main SPEAR control system whenever this becomes desirable.

Due to the variation of the main dipole field at injection an injection timing trigger with a precision of about 1 μ sec is required to keep the energy of the beam at ejection to SPEAR within tight tolerances. This trigger is to be locked to the main dipole field variation and is used to trigger the gun, linac and the injection septum and kicker. The timing trigger is derived from a pick up coil and a permally strip to give a signal when the magnetic field is reverted. A special delay unit will be also triggered from this timing signal to later produce the trigger for the ejection septum and kicker magnets.

For particle beam monitoring a current monitor will be installed to measure the beam intensity. Beam position monitors will detect the beam orbit and provide the signals to correct it. During particle acceleration in the booster it will be desirable to control the beam orbit to adjust for slight variations in the magnetic fields of the individual magnets. Trim magnets as part of the quadrupoles or bending magnets will be used in conjunction with the beam position monitors to dynamically control the beam orbit when needed.

The magnet current during acceleration will be computer controlled and a feedback system which monitors the betatron oscillation frequency will be used to keep the betatron tunes of the synchrotron constant during energy ramping.

The controls for the RF system will be similar to those developed for the storage rings PEP and SPEAR.

The linac controls contain mostly a timing system, as well as a phase and amplitude detection system which provides the signals for the purpose of phasing the klystrons. The timing system makes use of a signal from the master oscillator set precisely to a harmonic of the revolution frequency of the beam in the storage ring. From these signals the timing for the phasing of the linac RF, the synchrotron RF and for the chopper cavity are derived. A set of beam monitors, bending magnets and slits will be provided to control the beam energy and the beam energy spread before it is injected into the synchrotron.

For beam monitoring a DC current transformer will be used as well as beam position monitors to control the beam orbit. The magnet current during acceleration will be computer controlled and a feedback system which monitors the betatron oscillation will be used to keep the betatron tunes of the synchrotron constant during energy ramping. The controls for the RF system will be equal to the SPEAR storage ring system with the additional capability to change the klystron drive as required by the beam energy during acceleration. The linac controls contain mostly a timing system and a phase and amplitude detection system, which provides the signals for the purpose of phasing the klystrons. The booster timing system will tie into the SPEAR timing system to allow the filling of any arbitrary bunch pattern in the SPEAR storage ring.

3.2.6 Injection and Ejection

The proposed SPEAR injection system involves a series of injections and ejections into and out of the booster and into the SPEAR storage ring. The injection and ejection at the booster is relatively simple since no accumulation is attempted and therefore both injection and ejection is performed during one revolution time only. As a consequence only one kicker magnet and one septum magnet is needed for injection and the same for ejection. Obviously the design of these pulsed magnets is much simpler for the low injection energy of 100 MeV compared to the ejection energy of 3.0 GeV.

3.2.6.1 Ejection from the Booster Synchrotron

After acceleration of the particles to the storage ring energy an ejection process is triggered for the transfer of the beam to SPEAR. A fast full aperture kicker magnet in the booster synchrotron will deflect the beam into the magnetic aperture of a weak septum magnet. This septum magnet will be followed by a stronger septum magnet to finally deflect the beam out and away from the booster components into a beam transport system. The pulsed magnets required for this process are of conventional design and need no further R&D.

3.2.6.2 Beam Transport to SPEAR

The beam ejected from the booster synchrotron enters a short beam transport system leading into the nearby existing electron injection transport line. Where both beam lines merge a bending magnet will deflect the booster beam onto the existing path of the injection line. If no other modifications were contemplated this beam would then enter the SPEAR storage ring at the now existing entry point through existing injection components. Some existing pulsed magnets, however, would limit the injection energy to 2.3 GeV and therefore need to be replaced with more powerful components. A layout of this beam transport system is shown in Fig. 25. In this proposal we assume that the present 2.3 GeV pulsed magnet system will be replaced by a 3 GeV pulsed magnet system. To provide the operational feasibility of a low emittance configuration it is also proposed to replace the present two kicker magnet system by three kicker magnets. This is necessary to generate a matched beam bump for the low emittance configuration.

3.2.7 Utilities

The synchrotron will require electrical as well as mechanical utilities. An overview of existing and planned for utilities is shown in Figure 26 . The maximum total electrical power requirement at 3 GeV is about 1 MW although less than half that will be needed on average during operation. Of

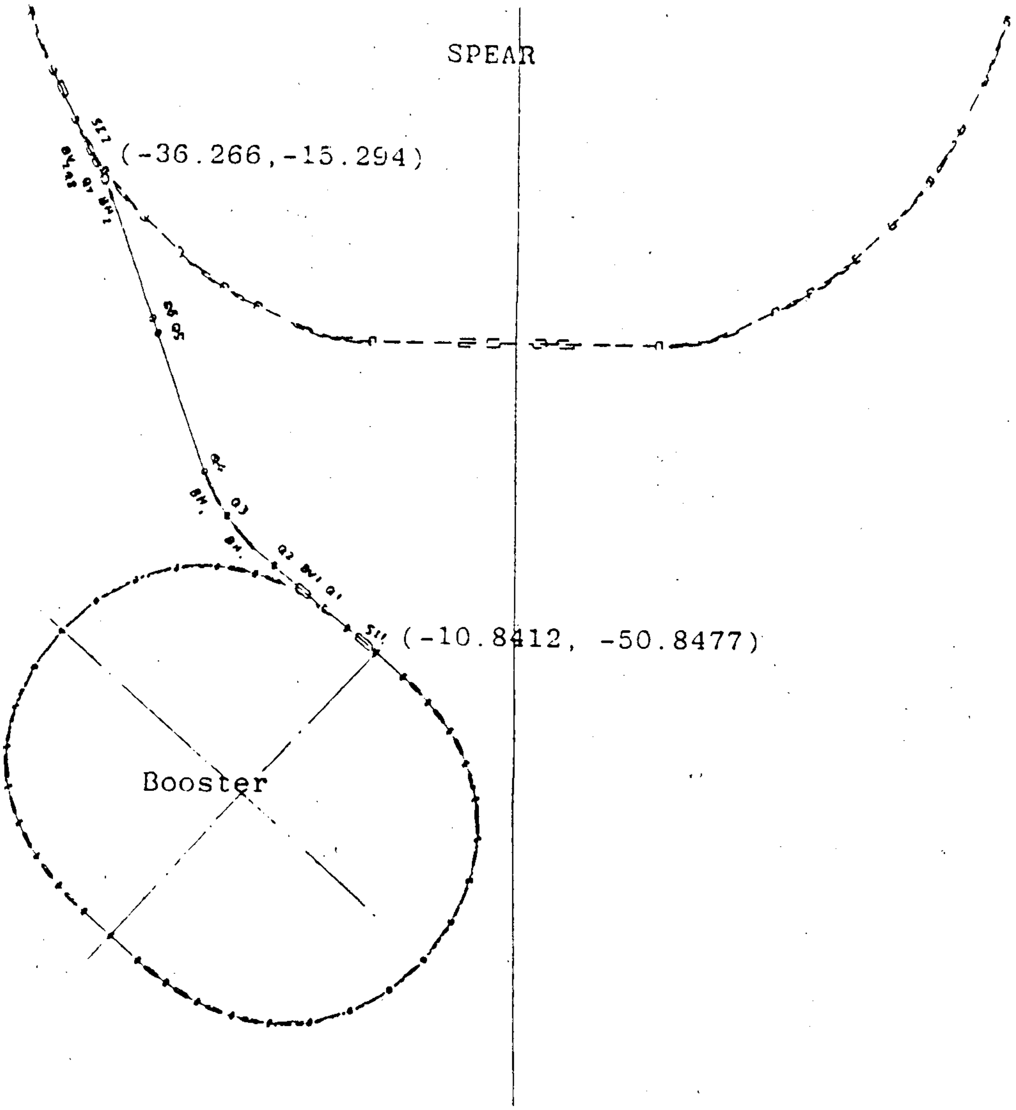


Fig. 25: Beam Transport Line from the Booster to SPEAR Tunnel

that about 300kW is for the RF-system and 400 kW for the magnets. The remainder for miscellaneous components including house power.

A separate 3 phase, 4 wire, 12 kV power source will be extended from an existing "H" frame, located located in the north-western corner of the north research yard, about 30 feet away from the booster ring tunnel (Figure 26). A new transformer and switch gear, located near the klystron power supply shelter, will reduce this power to 480 - 120/220 volt for general power distribution systems. Additional metering and switch gear is needed for the synchrotron as well as AC cabling for the klystron and magnet power supplies.

AC services including receptacles and lighting is required for the equipment shelters and the ring tunnel. Communications and fire alarm systems will be extended from the existing SPEAR/SSRL system.

Since only about half of the maximum power capacity will be used, on average, the LCW cooling systems are sized for 0.5 MW. A six inch stainless steel line, supplying 400 GPM of LCW, will be extended from a nearby source in the research yard (Figure 26).

Domestic water and compressed air will be supplied from nearby existing sources to serve the injector facility.

3.3 Shielding and Shelters

The linac preinjector and the synchrotron must be housed in a radiation safe shelter. The accelerators will be housed in an above-ground concrete tunnel, 2 feet thick to protect the outside world from radiation. The inside dimensions of the ring tunnel will be 7 feet high and 10 feet wide with a 7 feet aisle for easy access to the ring (Figure 27). There will be three access ways into the ring. Two can be used for component installation, while another access through the linac tunnel serves as an escape way for emergencies.

Additional concrete shielding blocks will be installed on top of the existing SPEAR tunnel along the injector line to eliminate present radiation concerns.

In addition to the accelerator tunnels there are several light weight shelters to house the linac klystrons, the synchrotron klystron with its variable

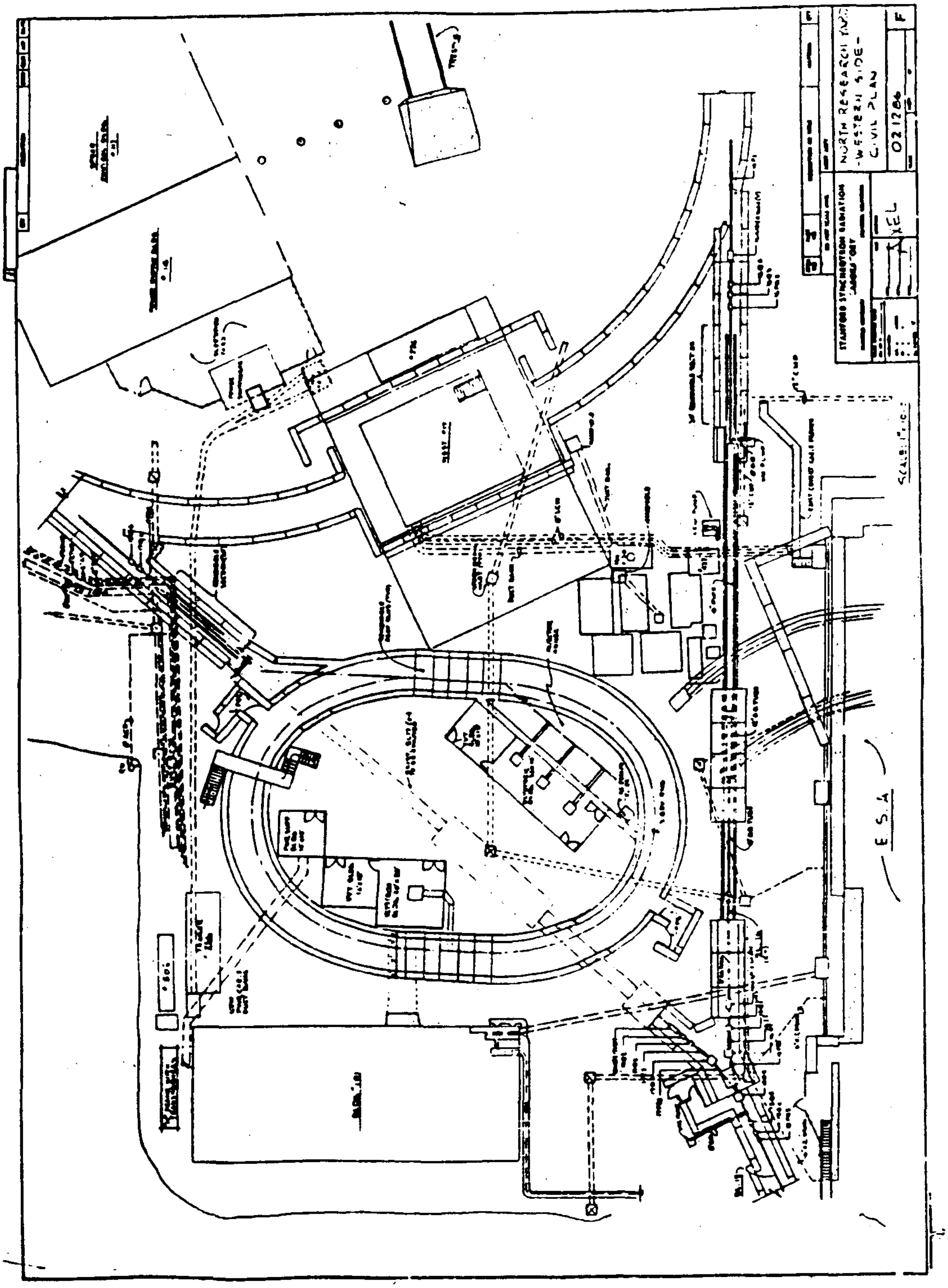


Fig. 26: Injector Utilities Plan

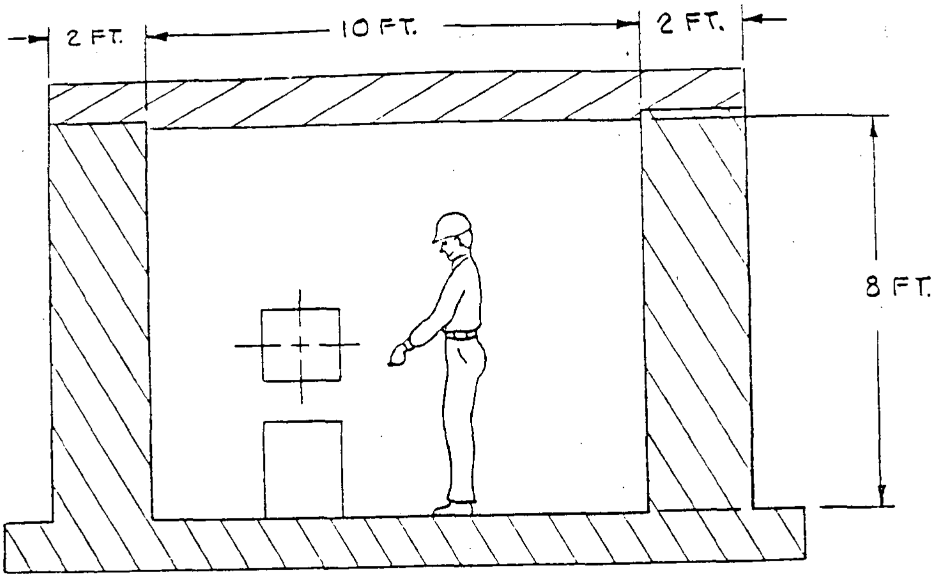


Fig. 27: Ring Shielding Cross Section

voltage transformer and high voltage box, the magnet power supplies and some local electronics.

All shelters will be constructed on a flat surface in part of the SLAC research yard next to the SPEAR storage ring (Figure 1). It is planned to keep the present electron beam line which crosses the synchrotron tunnel operational at least until the synchrotron is commissioned. This is possible since the existing injection line is on a higher elevation than the booster synchrotron beam lines by about 2 feet. The existing electron beam transport line, therefore, is no more than a small beam pipe just underneath the shielding roof where it crosses the ring tunnel.

Most of the ring tunnel walls will be constructed by poured reinforced concrete. It will, however, have removable roof blocks for easy installation of large equipment like the RF cavity.

3.4 Safety

Radiation safety around the SPEAR injector is provided by the passive shielding method as described above. In addition there will be radiation monitoring in accordance with present practice at SLAC and in the vicinity of the SPEAR shielding enclosure.

Personnel safety interlocks will be installed to prevent access to the ring enclosure during operation as well as to exclude beam from enclosures when personnel are present. These interlocks will be of the same design as those employed at SPEAR.

Safety rules will follow the Carlifornia safety code. During installation tunnel safety will be monitored by the SSRL safety group while the primary responsibility for providing and maintaining a safe environment lies with the head of the injector project. The safety group will monitor the safety of operations and review the safety aspects of equipment, structures and shielding associated with installation and operation.

Emergency power will be provided in the tunnel for lighting and protection of sensitive equipment.

All shelters designed such as to comply with the strict SLAC earthquake standards.

Fire safety has been coordinated with the local Palo Alto fire department to insure proper access. For small emergencies fire extinguishers will be located in each of the enclosures.

MGMT PLAN

4 Management Plan

The 3 GeV SPEAR Injector Project Management Plan is under separate cover inasmuch as the plan is subject to regular updating.

In brief, the Project Management Plan (PMP) describes in some detail, the SSRL management procedures that will be used to guide and monitor the Injector Project. The PMP is modeled, to a considerable extent, upon the approved SEP (I) Project Management Plan, plus the requirements of DOE Order 5700.4A.

The Injector Project PMP defines the responsibilities for reporting and review procedures for the project technical, cost and schedule baselines and specifies a system for effecting changes to the established baselines. Organizational realtionships between the Injector Project, SSRL, SLAC, Stanford University administration, the DOE Stanford Site Office (SSO), the DOE San Francisco Operations Office at Oakland (SAN) and the Office of Basic Energy Sciences (BES) are described in the PMP. The various responsibilities and authorities of these organizational units are defined in the plan. The Injector Project PMP also defines the technical specifications of the project and the related performance criteria.

A brief summary of the critical elements of the PMP is given in the following paragraphs.

SSRL will, through the Associate Director for the Accelerator Division and its staff, provide the leadership for directing and coordinating the design and construction activities. This group will have primary responsibility for the design, planning and execution of the project. A small administrative staff within this division will provide the planning, preparation and control of the budget, supervise the schedule and prepare reporting documents as required. These efforts will be supplemented by special assignment of personnel from other SSRL Divisions to the injector project as required. The implementation of the vacuum system for the injector is planned to be performed through the SSRL vacuum group. The SSRL administrative staff will be available for special functions like personnel matters, contract administration, receiving and inventory. Purchasing is expected to be done similar to present practice, through the SLAC purchasing department.

The SPEAR injector construction phase is assumed to start at the beginning of FY'1988. By that time an experienced group of engineers and designers will become available from the phase down of the construction effort for the 1.2 GeV high brilliance storage ring at the Stanford Photon Research Laboratory, SPRL.

The technical systems fabrication is planned to be performed to the maximum extent possible by outside industry through competitive bidding. This procedure also has been applied to the construction of the SPRL 1.2 GeV storage ring and it has been established that outside industry has the ability to fabricate the required components to the specified tolerances, schedule and within cost estimates. To make maximum use of industry's capabilities it is planned to perform all design by inhouse staff and invite bids on subsystems not to exceed the experience and capability of one vendor. The construction group then again takes responsibility for quality control, assembley, test and overall functioning of the systems. This mode of operation does not require the vendors to expand beyond the limits of their expertise and therfore allows many small businesses to effectively compete for contracts.

In this scenario it is obvious that SLAC shops will be invited to participate in the fabrication of injector components as such resouces become available and don't interfere with other SLAC activities.

WBS (Level 3) for the SPEAR Injector System

1 The 3 GeV Spear Injector System

  1.1 Special Facilities

    1.1.0 Non Technical Facilities
    1.1.1 Electrical Services
    1.1.2 Mechanical Services
    1.1.3 Safety Systems
    1.1.4 Preinjector
    1.1.5 Magnet System
    1.1.6 Vacuum System
    1.1.7 RF System
    1.1.8 Instrumentation and Control
    1.1.9 Injection and Ejection

  1.2 Project Management and Administration

    1.2.1 Technical Project Management
    1.2.2 Administrative Services

WBS (Level 4) for the SPEAR Injector System

1 The 3 GeV Spear Injector System

- 1.1 Special Facilities
  - 1.1.0 Non Technical Facilities
    - 1.1.0.0 E D & I
    - 1.1.0.1 Site Preparation
    - 1.1.0.2 Shelters
  - 1.1.1 Electrical Services
    - 1.1.1.0 E D & I
    - 1.1.1.1 AC Services
  - 1.1.2 Mechanical Services
    - 1.1.2.0 E D & I
    - 1.1.2.1 LCW Cooling System
  - 1.1.3 Safety Systems
    - 1.1.3.1 Fire Safety
  - 1.1.4 Preinjector
    - 1.1.4.0 E D & I
    - 1.1.4.1 Gun Assembly
    - 1.1.4.2 Accelerator Sections
    - 1.1.4.3 Modulators
    - 1.1.4.4 Klystrons
    - 1.1.4.5 Controls
    - 1.1.4.6 Linac Vacuum
    - 1.1.4.7 Beam Diagnostics

- 1.1.5 Magnet System
    - 1.1.5.0 E D & I
    - 1.1.5.1 Magnets
    - 1.1.5.2 Magnet Support
    - 1.1.5.3 Alignment
    - 1.1.5.4 Magnet Measurement
    - 1.1.5.5 Magnet Power Supplies
- 1.1.6 Vacuum System
    - 1.1.6.0 E D & I
    - 1.1.6.1 Vacuum Chambers
    - 1.1.6.2 Pumping System
    - 1.1.6.3 Pressure Monitoring
    - 1.1.6.4 Cleaning/Installation
- 1.1.7 RF System
    - 1.1.7.0 E D & I
    - 1.1.7.1 RF Power Generation
    - 1.1.7.2 RF Cavity
    - 1.1.7.3 Low Level RF System
    - 1.1.7.4 Computer Interface
- 1.1.8 Instrumentation and Control
    - 1.1.8.0 E D & I
    - 1.1.8.1 Beam Diagnostics
    - 1.1.8.2 Control Systems
    - 1.1.8.3 Protection System
    - 1.1.8.4 Communications
- 1.1.9 Injection and Ejection
    - 1.1.9.0 E D & I
    - 1.1.9.1 Transport Lines

    - 1.1.9.2 Pulsed Magnets
    - 1.1.9.3 Instrumentation

- 1.2 Project Management and Administration
  - 1.2.1 Technical Project Management
    - 1.2.1.1 Technical Coordination
    - 1.2.1.2 Accelerator Physics
    - 1.2.1.3 Installation Coordination and Quality Control
  - 1.2.2 Administrative Services
    - 1.2.2.1 Project Planning and Budget Office
    - 1.2.2.2 SSRL Administration Services

WBS (Level 5) for the SPEAR Injector System

- 1 The 3 GeV Spear Injector System
  - 1.1 Special Facilities
    - 1.1.0 Non Technical Facilities
      - 1.1.0.0 E D & I
      - 1.1.0.1 Site Preparation
      - 1.1.0.2 Shelters
        - 1.1.0.2.1 Ring/Linac Tunnel
          - 1.1.0.2.1.1 Concrete Floor
          - 1.1.0.2.1.2 Ring Wall/Roof
        - 1.1.0.2.2 Equipment Shelter
          - 1.1.0.2.2.1 Ring Klystron
          - 1.1.0.2.2.2 Linac Klystrons
          - 1.1.0.2.2.3 PS/VVT Shelter
    - 1.1.1 Electrical Services
      - 1.1.1.0 E D & I
      - 1.1.1.1 AC Services
    - 1.1.2 Mechanical Services
      - 1.1.2.0 E D & I
      - 1.1.2.1 LCW Cooling System
    - 1.1.3 Safety Systems
      - 1.1.3.1 Fire Safety

1.1.4.1.2 RF/Cavity System
1.1.4.1.3 Focusing and Steering
1.1.4.1.4 Momentum Filter
1.1.4.1.5 Beam Diagnostics
1.1.4.1.6 Vacuum System

1.1.4.2 Accelerator Sections
1.1.4.3 Modulators

1.1.4.3.1 HV Power Supply
1.1.4.3.2 Pulse Forming Network (PFN)
1.1.4.3.3 Controls

1.1.4.4 Klystrons

1.1.4.4.1 Tube
1.1.4.4.2 Focusing
1.1.4.4.3 Tank and Cable

1.1.4.5 Controls

1.1.4.5.1 Master Oscillator
1.1.4.5.2 RF Drive
1.1.4.5.3 Timing System
1.1.4.5.4 Diagnostics

1.1.4.6 Linac Vacuum
1.1.4.7 Beam Diagnostics

1.1.4.7.1 Beam Position Monitors
1.1.4.7.2 Current/Charge Monitor
1.1.4.7.3 Beam Steering
1.1.4.7.4 Beam Focusing
1.1.4.7.5 Analyzing Station

1.1.5 Magnet System

1.1.5.1 Magnets

        - 1.1.5.1.1 Bending Magnets
        - 1.1.5.1.2 Quadrupoles
        - 1.1.5.1.3 Spec. Magnets

    - 1.1.5.2 Magnet Support
    - 1.1.5.3 Magnet Alignment
    - 1.1.5.4 Magnetic Measurement
    - 1.1.5.5 Magnet Power Supplies

- 1.1.6 Vacuum System
    - 1.1.6.1 Vacuum Chambers
        - 1.1.6.1.1 Bending Chambers
        - 1.1.6.1.2 Quad Chambers
        - 1.1.6.1.3 Straight Section Chambers
    - 1.1.6.2 Pumping System
        - 1.1.6.2.1 Roughing System
        - 1.1.6.2.2 Ion Pumping System
    - 1.1.6.3 Pressure Monitoring
    - 1.1.6.4 Cleaning/Installation

- 1.1.7 RF System
    - 1.1.7.1 RF Power Generation
        - 1.1.7.1.1 350 MHz Klystron
        - 1.1.7.1.2 Klystron HV Supply
    - 1.1.7.2 RF Cavity
    - 1.1.7.3 Low Level RF System
    - 1.1.7.4 Computer Interface

- 1.1.8 Instrumentation and Control
    - 1.1.8.1 Beam Diagnostics
        - 1.1.8.1.1 Beam Position Monitors

1.1.8.1.2 Intensity Monitoring
1.1.8.1.3 Timing System

1.1.8.2 Control Systems

1.1.8.2.1 Interface/Controllers
1.1.8.2.2 Software
1.1.8.2.3 Racks, Cables, Trays
1.1.8.2.4 Computer Interface

1.1.8.3 Protection System
1.1.8.4 Communications

1.1.9 Injection and Ejection

1.1.9.1 Transport Lines

1.1.9.1.1 Linac Booster
1.1.9.1.2 Booster-SPEAR 3.0 GeV
1.1.9.1.3 Power Supplies
1.1.9.1.4 Vacuum System

1.1.9.2 Pulsed Magnets

1.1.9.1.1 Kicker Magnets
1.1.9.1.2 Septum Magnets

1.1.9.3 Instrumentation

1.2 Project Management and Administration

1.2.1 Technical Project Management

1.2.1.1 Technical Coordination
1.2.1.2 Accelerator Physics
1.2.1.3 Installation Coordination and Quality Control

1.2.2 Administrative Services

1.2.2.1 Project Planning and Budget Office
1.2.2.2 SSRL Administration Services

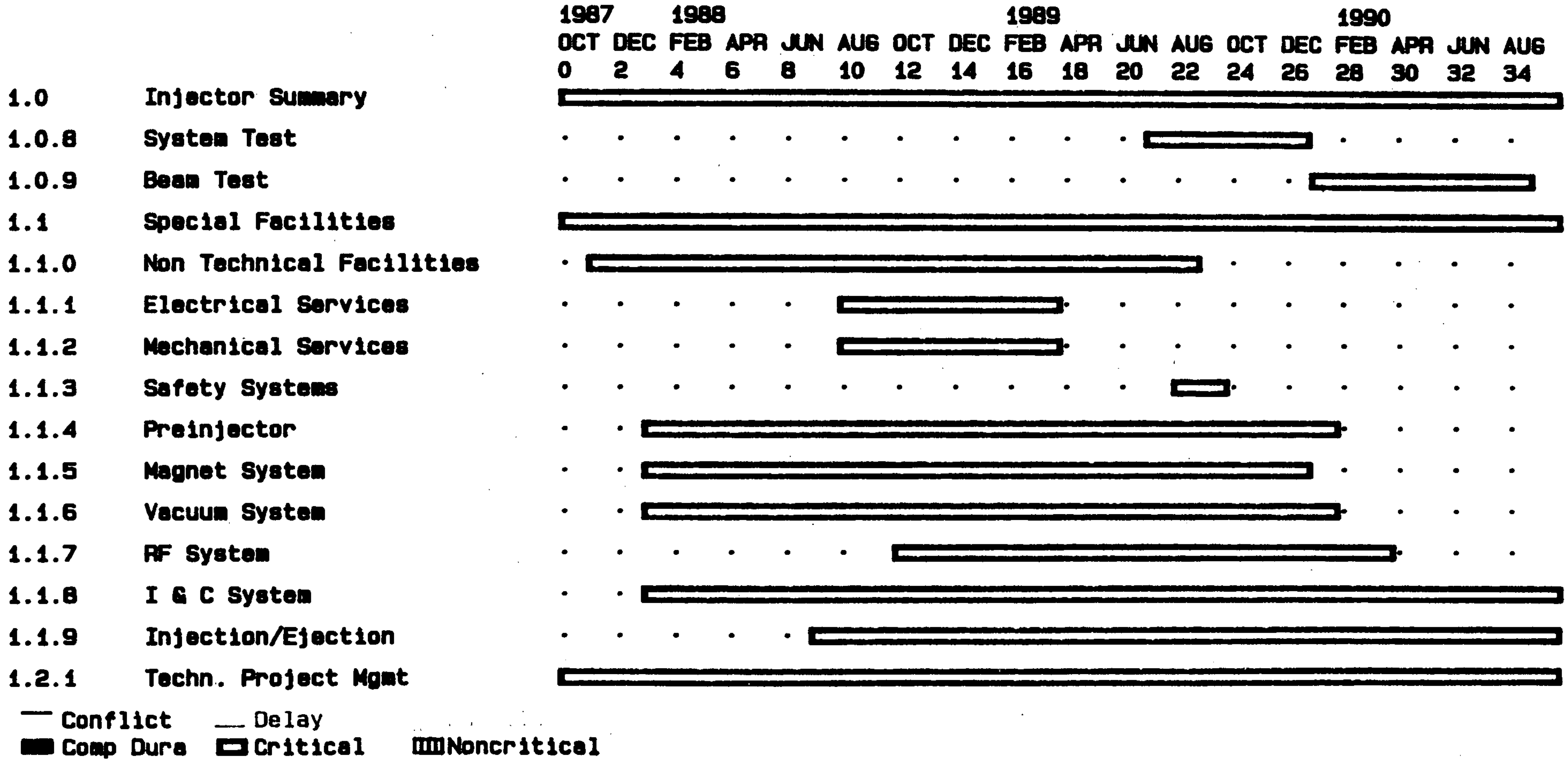
SCHEDULES

6 Schedule

A project schedule has been developed on the assumptions that construction funds become available at $ 3.0 M for FY'88, $7.5 M for FY'89 and, $3.0 M for FY'90. With these assumption the injector system can be completed within 27 months. At that time, January 1990, beam tests in the preinjector linac are scheduled to be completed and beam tests in the booster synchrotron can begin. SPEAR injection tests could begin as early as March 1990. The actual start of the SPEAR injection tests, however, will depend on the SPEAR running schedule to minimize interference with the ongoing SSRL and high energy physics programs.

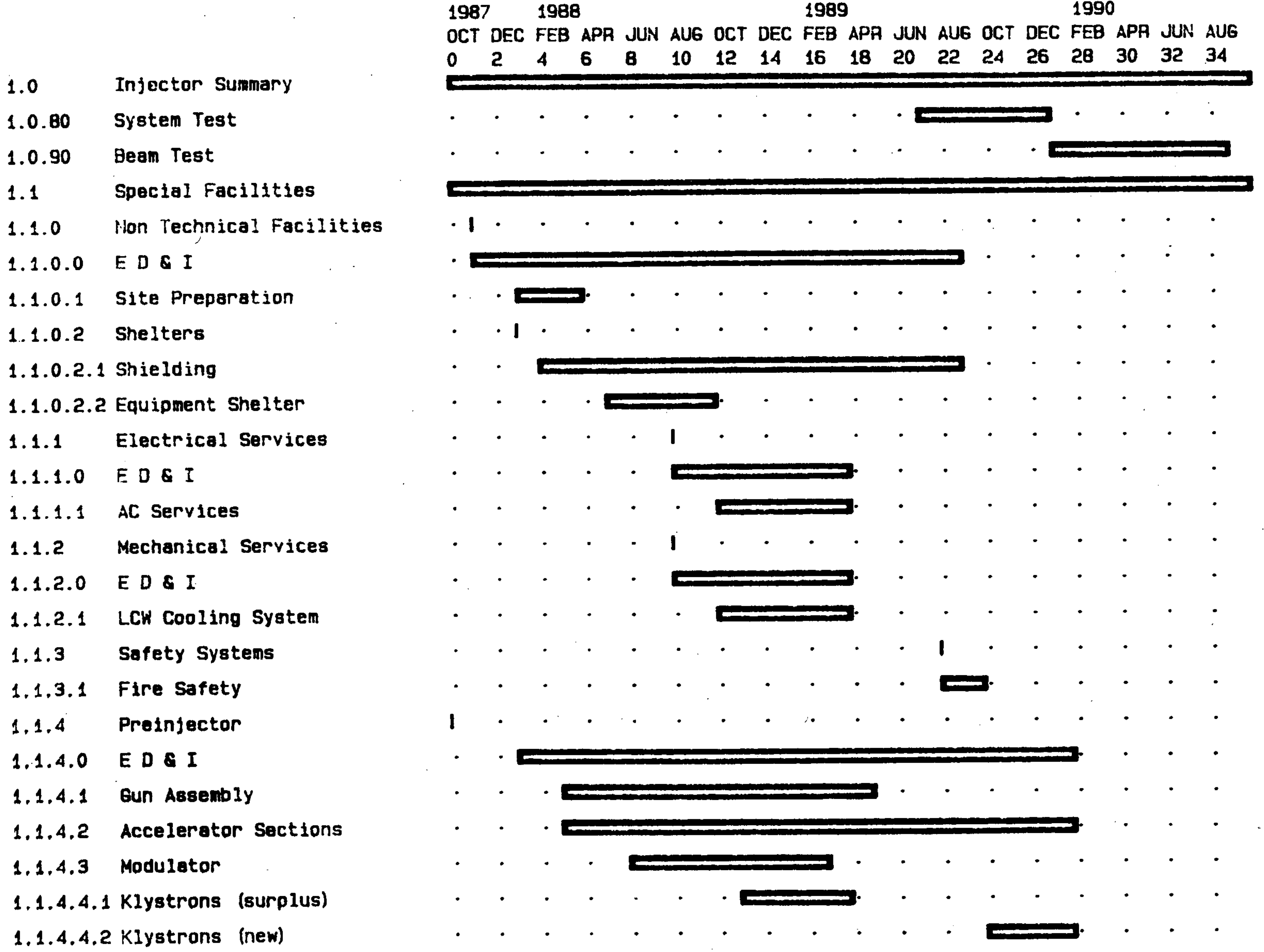
A summary as well as a more detailed schedule is shown in the following pages. A list of general project milestones as well as critical milestones is given in this section.

GANTT CHART REPORT - Current Date: 08-11-87
Summarize Level: 5
3 GeV SPEAR Injector



GANTT CHART REPORT - Current Date: 08-11-87

3 GeV SPEAR Injector



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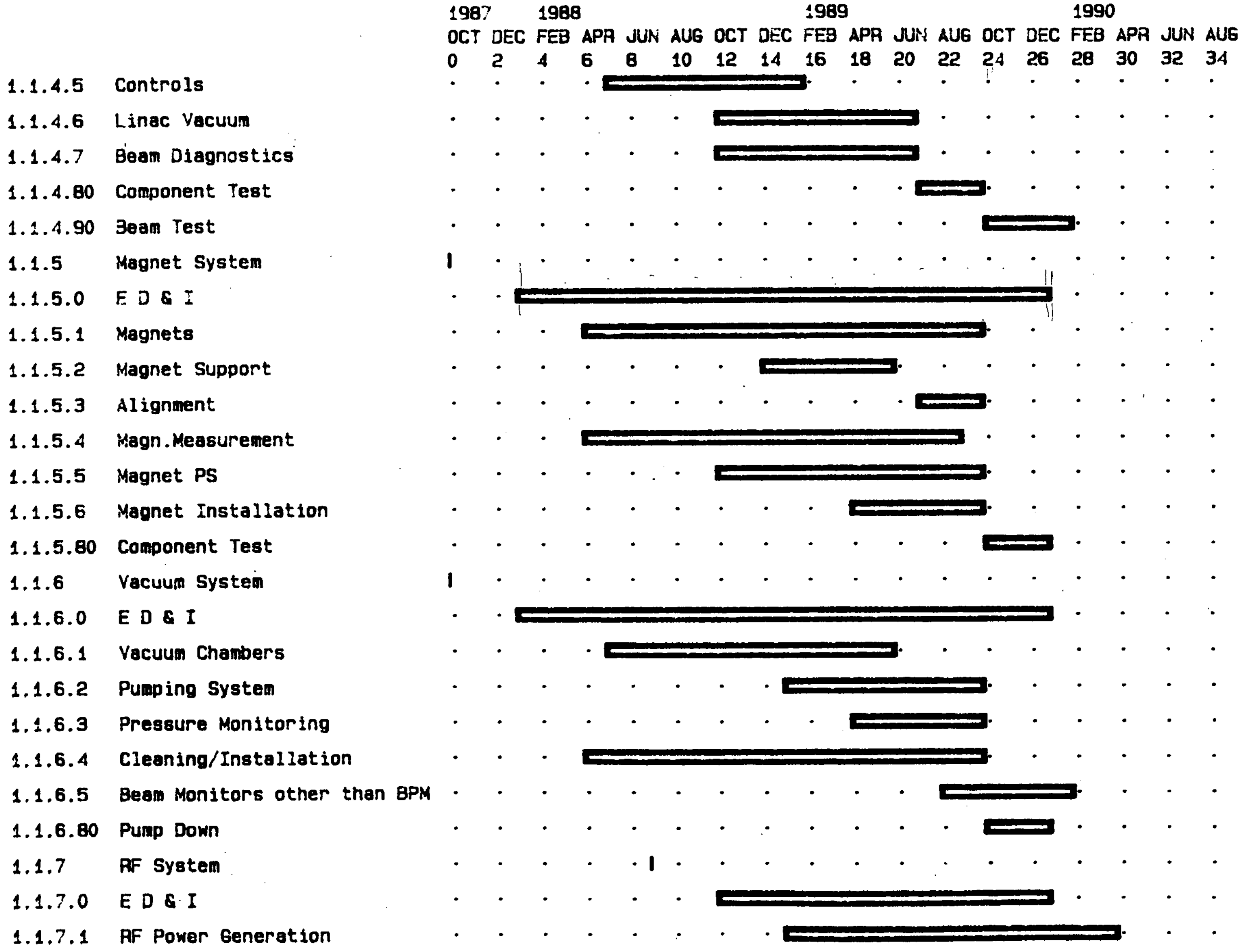
3 GeV SPEAR Injector



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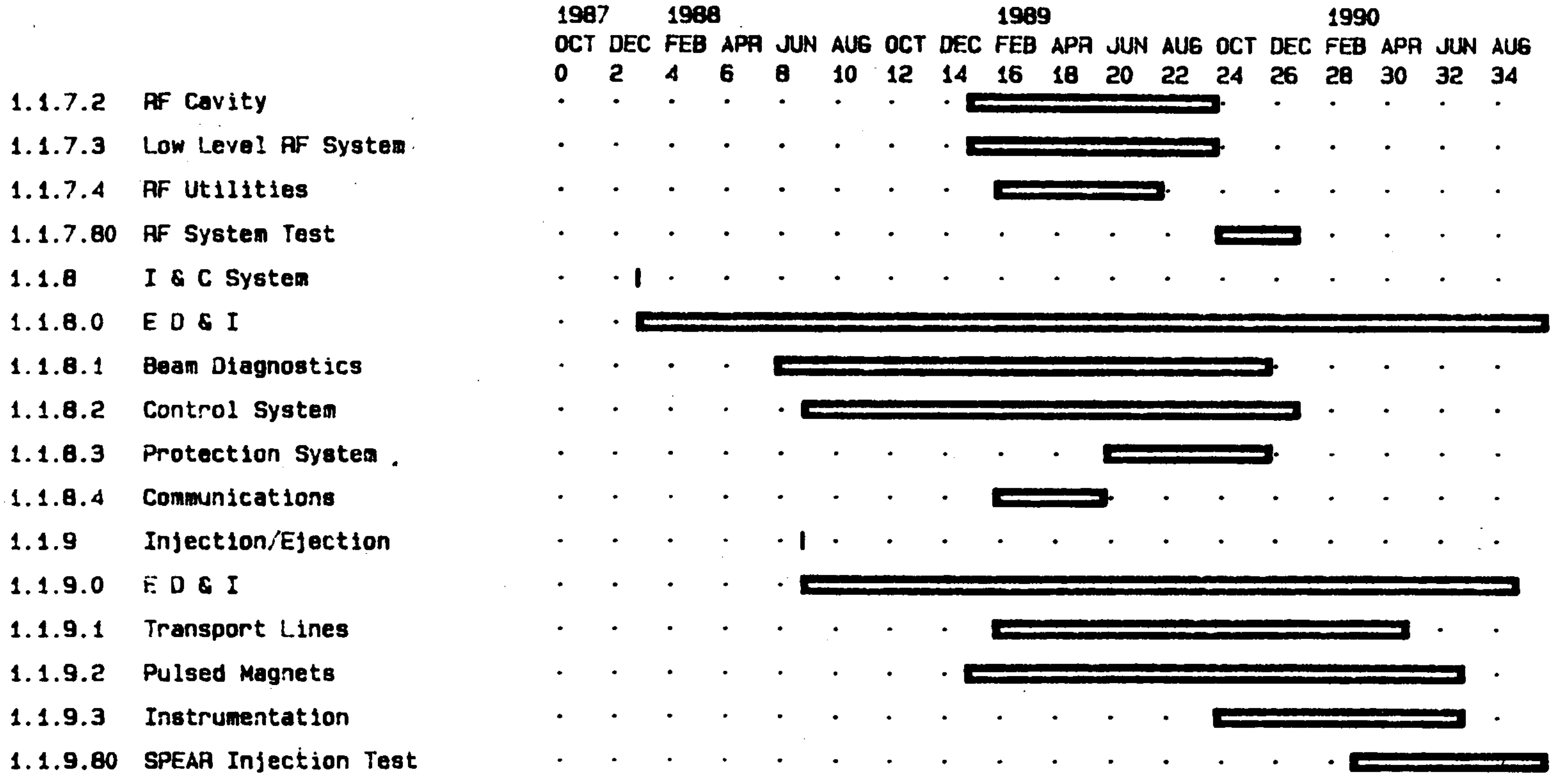
3 GeV SPEAR Injector



Booster Milestones

	Milestones	Date	On Critical Path
Funding	Start	10/87	YES
Facilities	Equipment Shelters	10/88	YES
	Electrical Utilities	4/89	
	Mechanical Utilities	4/89	
	Shielding	9/89	YES
Linac	Order Accelerating Sections	5/88	YES
	Gun Test (Mod & Klystrons)	5/89	
	Linac Beam Test	10/89	YES
Magnet	Place Main Magnets Orders	4/88	
	Order Big Power Supplies	10/88	
	Power Supply Test	10/89	YES
	Start Magnet Installation	4/89	YES
	Finish Magnet Installation	10/89	YES
	System Tests	10/89	YES
Vacuum	Place Vacuum Chamber Order	5/88	
	Install Vacuum Chambers	2/89	
	Pumpdown	10/89	YES
RF	Cavity Cold Test	10/88	
	RF System Test	10/89	YES
IC	Complete Timing System	9/89	
	Complete Linac Diagnostics	10/89	YES
	Systems Tests Complete	12/89	YES
Inject./Eject.	Complete Kicker Magnet	10/89	
	System Test (Contingent on SPEAR schedule)	3/90	YES
Project	Start Commissioning Booster	1/90	
	Start Injection into SPEAR (Contingent on SPEAR schedule)	5/90	7/90
	Project Complete	9/90	YES

COSTS

7. COST ESTIMATE

This section of the CDR presents summarized and detailed cost estimates of the 3 GeV SPEAR Injector Project. Computer-generated rounding-off errors account for slight differences between some of the estimate totals.

7.1 OBLIGATIONS AND COSTS ESTIMATE SUMMARY

The following table shows the summary of the estimated obligations and costs (in thousands) for the three-year project. This arrangement of the estimated obligations and costs corresponds to the Construction Project Data Sheets.

TITLE	FY88		FY89		FY90		
	OBS	COSTS	OBS	COSTS	OBS	COSTS	TOTAL
3 GEV INJECTOR							
Special Facil	1,878	1,729	5,315	5,342	1,848	1,970	9,041
Engrng & Design	504	504	1,148	1,148	336	336	1,988
Proj Mgmt & Adm	187	187	183	183	220	220	590
Subtotal	2,569	2,420	6,646	6,673	2,404	2,526	11,619
Contingencies	431	432	854	853	596	596	1,881
Total	3,000	2,852	7,500	7,526	3,000	3,122	13,500

7.2 ESCALATION FACTORS

The FY1986 baseline costs were escalated with the escalation factors shown below. The source for these factors is the Anticipated Economic Escalation Rates for Energy Research Construction Projects, August 1986 update.

	RATE	FACTOR
FY86 - FY87	2.5%	1.025
FY87 - FY88	4.0%	1.066
FY88 - FY89	4.8%	1.117
FY89 - FY90	5.3%	1.176

7.3 CONTINGENCIES

The contingencies on the various tasks under the project have been estimated separately for different systems depending on the complexity and the exposure to fluctuating economic factors. Systems which are very well defined and for which local industry has been tested carry a minimum 15% contingency. The booster RF system, being an exact replication of the system for the Stanford Photon Research Lab storage ring, carries a contingency of only 10%. A larger (25%) contingency must be applied to the Instrumentation and Control (I&C) system and part of the injection and ejection systems since both require incorporation into existing SPEAR systems. Traditionally such incorporations into existing facilities reveal undocumented boundary and interface conditions that require additional funds and design effort.

7.4 LEVELS 3 AND 4 ESTIMATED OBLIGATIONS AND COSTS

The tables on the following three pages show the estimated FY1986 Baseline Costs and the estimated annual (extended) obligations and costs at Levels 3 and 4, all rounded to thousands.

7.3 FY 1986 BASELINE COSTS

The baseline costs were estimated in FY1986 dollars and are presented in detail following the Level 3 and 4 TEC estimates.

Most of the baseline estimates were based on costs for similar components in recent projects such as the damping rings at SLAC, the 1.2 GeV storage ring under construction at the Stanford Photon Research Laboratory (SPRL) and on engineering estimates by technical support groups at SSRL and SLAC.

INJECT4 SPEAR 3 GEV INJECTOR EXTENDED OBLIGATIONS AND COSTS
DISK 4/4B
8/11/87

A116

		FY86 BASE	FY 1988		FY 1989		FY 1990		TOTAL	
			OBS	COSTS	OBS	COSTS	OBS	COSTS	OBS	COSTS
	LEVEL 3 SUMMARY									
1	3 GeV SPEAR INJECTOR									
1.1	SPECIAL FACILITIES									
1.1.0	NON-TECH FACILITIES	679	482	433	252	252	0	49	734	734
1.1.1	ELECTRICAL SERVICES	376	19	19	401	401	0	0	420	420
1.1.2	MECHANICAL SERVICES	309	19	19	325	325	0	0	344	344
1.1.3	SAFETY SYSTEMS	20	0	0	18	18	5	5	23	23
1.1.4	PREINJECTOR	1,292	566	466	597	694	266	269	1,429	1,429
1.1.5	MAGNET SYSTEMS	1,919	587	587	1,472	1,402	59	129	2,118	2,118
1.1.6	VACUUM SYSTEM	658	267	267	411	411	46	46	724	724
1.1.7	RF SYSTEM	756	0	0	643	643	213	213	856	856
1.1.8	INST & CONTROL	1,213	230	230	935	935	190	190	1,355	1,355
1.1.9	INJECTION/EJECTION	1,622	28	28	925	925	904	904	1,857	1,857
	SUBTOTAL 1.1	8,344	2,198	2,049	5,979	6,006	1,683	1,805	9,860	9,860
1.2	PROJECT MANAGEMENT AND ADMINISTRATION									
1.2.0	TECH PROJ MGMT	1,195	242	242	531	531	578	578	1,351	1,351
1.2.1	ADMIN SERVICES	365	129	129	136	136	143	143	408	408
	SUBTOTAL 1.2	1,560	371	371	667	667	721	721	1,759	1,759
TOTAL WITHOUT CONTINGENCY		10,404	2,569	2,420	6,646	6,673	2,404	2,526	11,619	11,619
CONTINGENCY		1,676	431	432	854	853	596	596	1,881	1,881
TOTAL ESTIMATED COSTS (TEC)		12,080	3,000	2,852	7,500	7,526	3,000	3,122	13,500	13,500

R159

INJECT4 SPEAR 3 GEV INJECTOR EXTENDED OBLIGATIONS AND COSTS

DISK 4/4B

8/11/87

			FY 1988		FY 1989		FY 1990		TOTAL	
		FY86 BASE	OBS	COSTS	OBS	COSTS	OBS	COSTS	OBS	COSTS
A5	LEVEL 4									
1	3 GeV SPEAR INJECTOR									
1.1	SPECIAL FACILITIES									
1.1.0	NON-TECHNICAL FACILITIES									
1.1.0.0	ED&I	58	31	31	32	32	0	0	63	63
1.1.0.1	Site Preparation	40	42	42	0	0	0	0	42	42
1.1.0.2	Shelters	581	409	360	220	220	0	49	629	629
	Subtotal	679	482	433	252	252	0	49	734	734
1.1.1	ELECTRICAL SERVICES									
1.1.1.0	ED&I	52	19	19	39	39	0	0	58	58
1.1.1.1	AC Services	324	0	0	362	362	0	0	362	362
	Subtotal	376	19	19	401	401	0	0	420	420
1.1.2	MECHANICAL SERVICES									
1.1.2.0	ED&I	53	19	19	39	39	0	0	58	58
1.1.2.1	LCW Cooling Sys	256	0	0	286	286	0	0	286	286
	Subtotal	309	19	19	325	325	0	0	344	344
1.1.3	SAFETY SYSTEMS									
1.1.3.1	Fire Safety	20	0	0	18	18	5	5	23	23
1.1.4	PREINJECTOR									
1.1.4.0	ED&I	215	104	104	107	107	25	25	236	236
1.1.4.1	Gun Assy	158	76	76	98	98	0	0	174	174
1.1.4.2	Accel Sections	266	169	69	36	133	88	91	293	293
1.1.4.3	Modulators	300	161	161	166	166	0	0	327	327
1.1.4.4	Klystrons	153	0	0	26	26	153	153	179	179
1.1.4.5	Controls	95	56	56	47	47	0	0	103	103
1.1.4.6	Linac Vacuum	46	0	0	51	51	0	0	51	51
1.1.4.7	Beam Diagnostics	59	0	0	66	66	0	0	66	66
	Subtotal	1,292	566	466	597	694	266	269	1,429	1,429
1.1.5	MAGNET SYSTEM									
1.1.5.0	ED&I	400	162	162	221	221	59	59	442	442
1.1.5.1	Magnets	733	298	298	506	506	0	0	804	804
1.1.5.2	Magnet Suprt	218	70	70	170	170	0	0	240	240
1.1.5.3	Magnet Align	50	0	0	56	56	0	0	56	56
1.1.5.4	Magnetic Measure	98	57	57	49	49	0	0	106	106
1.1.5.5	Power Supls	337	0	0	377	307	0	70	377	377
1.1.5.6	Magnet Install	83	0	0	93	93	0	0	93	93
	Subtotal	1,919	587	587	1,472	1,402	59	129	2,118	2,118
1.1.6	VACUUM SYSTEM									
1.1.6.0	ED&I	162	65	65	90	90	24	24	179	179
1.1.6.1	Vacuum Chambers	147	125	125	34	34	0	0	159	159
1.1.6.2	Pumping Sys	88	0	0	98	98	0	0	98	98

INJECT4 SPEAR 3 GEV INJECTOR EXTENDED OBLIGATIONS AND COSTS
DISK 4/4B
8/11/87

			FY 1988		FY 1989		FY 1990		TOTAL	
		FY86 BASE	OBS	COSTS	OBS	COSTS	OBS	COSTS	OBS	COSTS
1.1.6.3	Press Monitor	11	0	0	12	12	0	0	12	12
1.1.6.4	Clean/Install	177	63	63	132	132	0	0	195	195
1.1.6.5	Beam Monitor	73	14	14	45	45	22	22	81	81
	Subtotal	658	267	267	411	411	46	46	724	724
1.1.7	RF SYSTEM									
1.1.7.0	ED&I	230	0	0	206	206	54	54	260	260
1.1.7.1	RF Power	236	0	0	112	112	159	159	271	271
1.1.7.2	RF Cavities	88	0	0	98	98	0	0	98	98
1.1.7.3	Low Level RF Driv	183	0	0	205	205	0	0	205	205
1.1.7.4	RF Utilities	19	0	0	22	22	0	0	22	22
	Subtotal	756	0	0	643	643	213	213	856	856
1.1.8	INSTRUMENTATION & CONTROL									
1.1.8.0	ED&I	378	76	76	296	296	50	50	422	422
1.1.8.1	Beam Diagnostics	322	76	76	243	243	39	39	358	358
1.1.8.2	Control System	437	78	78	325	325	86	86	489	489
1.1.8.3	Protection Sys	64	0	0	57	57	15	15	72	72
1.1.8.4	Communications	12	0	0	14	14	0	0	14	14
	Subtotal	1,213	230	230	935	935	190	190	1,355	1,355
1.1.9	INJECTION & EJECTION									
1.1.9.0	ED&I	237	28	28	118	118	124	124	270	270
1.1.9.1	Transport Lines	798	0	0	391	391	528	528	919	919
1.1.9.2	Pulsed Magnets	546	0	0	416	416	203	203	619	619
1.1.9.3	Instrumentation	41	0	0	0	0	49	49	49	49
	Subtotal	1,622	28	28	925	925	904	904	1,857	1,857
	SUBTOTAL 1.1	8,844	2,198	2,049	5,979	6,006	1,683	1,805	9,860	9,860
1.2	PROJECT MANAGEMENT AND ADMINISTRATI									
1.2.1	TECHNICAL PROJECT MANAGMENT									
1.2.1.1	Technical Coordin	420	149	149	143	143	178	178	470	470
1.2.1.2	Accelerator Physi	173	61	61	40	40	93	93	194	194
1.2.1.3	QC & Install Coor	602	32	32	348	348	307	307	687	687
	Subtotal	1,195	242	242	531	531	578	578	1,351	1,351
1.2.2	ADMINISTRATIVE SERVICES									
1.2.2.1	Proj Plan/Bud Off	257	91	91	96	96	101	101	288	288
1.2.2.2	SSRL Admin Servic	108	38	38	40	40	42	42	120	120
	Subtotal	365	129	129	136	136	143	143	408	408
	SUBTOTAL 1.2	1,560	371	371	667	667	721	721	1,759	1,759
TOTAL W/O CONTINGENCY		10,404	2,569	2,420	6,646	6,673	2,404	2,526	11,619	11,619
CONTINGENCY		1,676	431	432	854	853	596	596	1,881	1,881
TEC (R115)		12,080	3,000	2,852	7,500	7,526	3,000	3,122	13,500	13,500

Base Line Cost Estimate (FY'86 Dollars)

Component/Activity	WBS	Base Line Budget by Systems			Base Line Cost FY'86 Dollars			
		Materials	Labor	Total	1988	1989	1990	3 Year Summary
Non Tech. Systems								
E D & I	1.1.0.0	0	57,703	57,703	28,852	28,852	0	57,703
Site Preparation	1.1.0.1	18,890	20,922	39,812	39,812	0	0	39,812
Shelters	1.1.0.2	544,888	36,280	581,168	384,077	197,091	0	581,168
Electr. Services								
E D & I	1.1.1.0	0	52,491	52,491	17,497	34,994	0	52,491
AC Services	1.1.1.1	223,487	100,872	324,359	0	324,359	0	324,359
Mechan. Services								
E D & I	1.1.2.0	0	52,828	52,828	17,609	35,219	0	52,828
LCW Cooling System	1.1.2.1	174,935	81,096	256,031	0	256,030	0	256,030
Safety Systems				0				
Fire Safety	1.1.3.1	20,000	0	20,000	0	15,830	4,170	20,000
Preinjector								
E D & I	1.1.4.0	0	214,709	214,709	97,597	95,641	21,471	214,709
Gun Assembly	1.1.4.1	113,330	45,055	158,384	70,909	87,475	0	158,384
Accel. Sections	1.1.4.2	246,354	19,192	265,546	158,304	32,242	75,000	265,546
Modulators	1.1.4.3	224,667	75,076	299,743	151,400	148,342	0	299,743
Klystrons	1.1.4.4	128,601	24,724	153,325	0	23,601	129,724	153,325
Controls	1.1.4.5	88,308	6,476	94,784	52,658	42,126	0	94,784
Linac Vacuum	1.1.4.6	42,235	3,286	45,521	0	45,521	0	45,521
Beam Diagnostics	1.1.4.7	44,731	14,302	59,032	0	59,032	0	59,032
Magnet System								
E D & I	1.1.5.0	0	400,049	400,049	151,858	198,186	50,006	400,049
Magnets	1.1.5.1	662,209	70,631	732,839	279,613	453,226	0	732,839
Magnet Support	1.1.5.2	204,634	13,508	218,142	65,681	152,461	0	218,142
Magnet Alignment	1.1.5.3	21,925	27,988	49,913	0	49,913	0	49,913
Magnetic Measurem.	1.1.5.4	50,050	47,691	97,741	53,909	43,832	0	97,741
Power Supplies	1.1.5.5	286,405	50,951	337,356	0	337,356	0	337,356
Magnet Install.	1.1.5.6	13,050	70,189	83,239	0	83,239	0	83,239
Vacuum System								
E D & I	1.1.6.0	0	161,571	161,571	60,589	80,785	20,196	161,571
Vacuum Chambers	1.1.6.1	109,028	38,117	147,145	116,837	30,307	0	147,145
Pumping System	1.1.6.2	87,571	0	87,571	0	87,571	0	87,571
Pressure Monitor.	1.1.6.3	10,704	0	10,704	0	10,704	0	10,704
Cleaning/Install.	1.1.6.4	71,903	104,741	176,643	58,881	117,762	0	176,643
Beam Monitoring	1.1.6.5	37,676	34,914	72,590	13,093	40,659	18,838	72,590
RF System								
E D & I	1.1.7.0	0	230,477	230,477	0	184,382	46,095	230,477
RF Power	1.1.7.1	211,783	23,763	235,546	0	100,546	135,000	235,546
RF Cavities	1.1.7.2	60,484	27,237	87,721	0	87,721	0	87,721
Low Level RF Drive	1.1.7.3	153,557	29,713	183,270	0	183,270	0	183,270
RF Utilities	1.1.7.4	17,265	2,123	19,388	0	19,388	0	19,388
I & C System								
E D & I	1.1.8.0	0	378,386	378,386	70,947	264,870	42,568	378,386
Beam Diagnostics	1.1.8.1	226,087	95,899	321,986	71,553	217,476	32,958	321,986
Control System	1.1.8.2	230,047	206,706	436,753	72,792	291,169	72,792	436,753
Protection System	1.1.8.3	35,611	28,020	63,631	0	50,905	12,726	63,631
Communications	1.1.8.4	7,500	4,670	12,170	0	12,170	0	12,170
Injection/Ejection								
E D & I	1.1.9.0	0	237,221	237,221	26,358	105,431	105,431	237,221
Transport Lines	1.1.9.1	580,503	217,958	798,461	0	349,864	448,597	798,461
Pulsed Magnets	1.1.9.2	434,562	111,175	545,737	0	372,868	172,868	545,737
Instrumentation	1.1.9.3	34,944	6,476	41,420	0	0	41,420	41,420
Techn. Project Mgmt.								
Tech. Coordination	1.2.1.1	66,048	353,888	419,936	139,979	128,183	151,775	419,936
Accel. Physics	1.2.1.2	9,900	162,952	172,853	57,618	35,891	79,344	172,853
Inst.Coord/Qal.Con	1.2.1.3	217,667	384,766	602,433	30,000	311,216	261,216	602,433
Administr. Services								
Planning Office	1.2.2.1	44,500	212,295	256,795	85,598	85,598	85,598	256,795
SSRL Admin. Serv.	1.2.2.2	0	107,627	107,627	35,876	35,876	35,876	107,627
Sub Totals w/o Cont.		5,756,038	4,646,710	10,402,748	2,409,895	5,949,181	2,043,672	10,402,748
Project Contingency		927,952	749,113	1,677,065	404,363	765,233	507,469	1,677,065
Base Line Cost Est.		6,683,990	5,395,823	12,079,813	2,814,259	6,714,414	2,551,141	12,079,813

Base Line Cost Estimate (FY'86 and then years $)

Component/Activity	WBS	Base Line Estimate by Systems FY'86 K$			Base Line Cost Estimate (then years K$)			
		Materials	Labor	Total	1988	1989	1990	Total
					Escalation Factors: 1.066	1.117	1.176	
Non Tech. Systems								
E D & I	1.1.0.0	0	58	58	31	32	0	63
Site Preparation	1.1.0.1	19	21	40	42	0	0	42
Shelters	1.1.0.2	545	36	581	409	220	0	630
Electr. Services								
E D & I	1.1.1.0	0	52	52	19	39	0	58
AC Services	1.1.1.1	223	101	324	0	362	0	362
Mechan. Services								
E D & I	1.1.2.0	0	53	53	19	39	0	58
LCW Cooling System	1.1.2.1	175	81	256	0	286	0	286
Safety Systems								
Fire Safety	1.1.3.1	20	0	20	0	18	5	23
Preinjector								
E D & I	1.1.4.0	0	215	215	104	107	25	236
Gun Assembly	1.1.4.1	113	45	158	76	98	0	173
Accel. Sections	1.1.4.2	246	19	266	169	36	88	293
Modulators	1.1.4.3	225	75	300	161	166	0	327
Klystrons	1.1.4.4	129	25	153	0	26	153	179
Controls	1.1.4.5	88	6	95	56	47	0	103
Linac Vacuum	1.1.4.6	42	3	46	0	51	0	51
Beam Diagnostics	1.1.4.7	45	14	59	0	66	0	66
Magnet System								
E D & I	1.1.5.0	0	400	400	162	221	59	442
Magnets	1.1.5.1	662	71	733	298	506	0	804
Magnet Support	1.1.5.2	205	14	218	70	170	0	240
Magnet Alignment	1.1.5.3	22	28	50	0	56	0	56
Magnetic Measurem.	1.1.5.4	50	48	98	57	49	0	106
Power Supplies	1.1.5.5	286	51	337	0	377	0	377
Magnet Install.	1.1.5.6	13	70	83	0	93	0	93
Vacuum System								
E D & I	1.1.6.0	0	162	162	65	90	24	179
Vacuum Chambers	1.1.6.1	109	38	147	125	34	0	158
Pumping System	1.1.6.2	88	0	88	0	98	0	98
Pressure Monitor.	1.1.6.3	11	0	11	0	12	0	12
Cleaning/Install.	1.1.6.4	72	105	177	63	132	0	194
Beam Monitoring	1.1.6.5	38	35	73	14	45	22	82
RF System								
E D & I	1.1.7.0	0	230	230	0	206	54	260
RF Power	1.1.7.1	212	24	236	0	112	159	271
RF Cavities	1.1.7.2	60	27	88	0	98	0	98
Low Level RF Drive	1.1.7.3	154	30	183	0	205	0	205
RF Utilities	1.1.7.4	17	2	19	0	22	0	22
I & C System								
E D & I	1.1.8.0	0	378	378	76	296	50	422
Beam Diagnostics	1.1.8.1	226	96	322	76	243	39	358
Control System	1.1.8.2	230	207	437	78	325	86	488
Protection System	1.1.8.3	36	28	64	0	57	15	72
Communications	1.1.8.4	8	5	12	0	14	0	14
Injection/Ejection								
E D & I	1.1.9.0	0	237	237	28	118	124	270
Transport Lines	1.1.9.1	581	218	798	0	391	528	918
Pulsed Magnets	1.1.9.2	435	111	546	0	416	203	620
Instrumentation	1.1.9.3	35	6	41	0	0	49	49
Techn. Project Mgmt.								
Tech. Coordination	1.2.1.1	66	354	420	149	143	178	471
Accel. Physics	1.2.1.2	10	163	173	61	40	93	195
Inst.Coord/Qal.Con	1.2.1.3	218	385	602	32	348	307	687
Administr. Services								
Planning Office	1.2.2.1	45	212	257	91	96	101	288
SSRL Admin. Serv.	1.2.2.2	0	108	108	38	40	42	121
Sub Totals w/o Cont.		5,756	4,647	10,403	2,569	6,645	2,403	11,618
Project Contingency		928	749	1,677	431	855	597	1,883
Base Line Cost Est.		6,684	5,396	12,080	3,000	7,500	3,000	13,500

M & S, Labor and E D & I by Year (FY'86 $)

Component/Activity	WBS	M&S	FY'88 Labor	E D & I	Total
Non Tech. Systems	1.1.0	388	36	29	453
Electr. Services	1.1.1	0	0	17	17
Mechan. Services	1.1.2	0	0	18	18
Safety Systems	1.1.3	0	0	0	0
Preinjector	1.1.4	387	47	98	531
Magnet System	1.1.5	359	40	152	551
Vacuum System	1.1.6	127	62	61	249
RF System	1.1.7	0	0	0	0
I & C System	1.1.8	89	56	71	215
Injection/Ejection	1.1.9	0	0	26	26
Sub Tot Special Facilities	1.1	1,349	241	471	2,061
Techn. Project Mgmt.	1.2.1	55	172	0	228
Administr. Services	1.2.2	15	107	0	121
Sub Tot Project Mgmt./Admi	1.2	70	279	0	349
Sub Tot Base Cost		1,419	520	471	2,410
Project Contingency		238	87	79	404
Total Project	1.	1,657	607	550	2,814

M & S, Labor and E D & I by Year (FY'86 $)

Component/Activity	WBS	M&S	FY'89 Labor	E D & I	Total
Non Tech. Systems	1.1.0	176	21	29	226
Electr. Services	1.1.1	223	101	35	359
Mechan. Services	1.1.2	175	81	35	291
Safety Systems	1.1.3	16	0	0	16
Preinjector	1.1.4	322	117	96	534
Magnet System	1.1.5	879	241	198	1,318
Vacuum System	1.1.6	171	116	81	368
RF System	1.1.7	308	83	184	575
I & C System	1.1.8	343	229	265	837
Injection/Ejection	1.1.9	565	158	105	828
Sub Tot Special Facilities	1.1	3,178	1,146	1,028	5,352
Techn. Project Mgmt.	1.2.1	144	331	0	475
Administr. Services	1.2.2	15	107	0	121
Sub Tot Project Mgmt./Admi	1.2	159	438	0	597
Sub Tot Base Cost		3,337	1,584	1,028	5,949
Project Contingency		429	204	132	765
Total Project	1.	3,766	1,788	1,161	6,714

M & S, Labor and E D & I by Year (FY'86 $)

Component/Activity	WBS	M&S	FY'90 Labor	E D & I	Total
Non Tech. Systems	1.1.0	0	0	0	0
Electr. Services	1.1.1	0	0	0	0
Mechan. Services	1.1.2	0	0	0	0
Safety Systems	1.1.3	4	0	0	4
Preinjector	1.1.4	180	25	21	226
Magnet System	1.1.5	0	0	50	50
Vacuum System	1.1.6	19	0	20	39
RF System	1.1.7	135	0	46	181
I & C System	1.1.8	68	51	43	161
Injection/Ejection	1.1.9	485	177	105	768
Sub Tot Special Facilities	1.1	891	253	286	1,430
Techn. Project Mgmt.	1.2.1	94	398	0	492
Administr. Services	1.2.2	15	107	0	121
Sub Tot Project Mgmt./Admi	1.2	109	505	0	614
Sub Tot Base Cost		1,000	758	286	2,044
Project Contingency		248	188	71	507
Total Project	1.	1,249	946	357	2,551

M & S, Labor and E D & I by Year (then Year $)

		Escalation Factor:		1.066	
Component/Activity	WBS	M&S	FY'88 Labor	E D & I	Total
Non Tech. Systems	1.1.0	413	39	31	483
Electr. Services	1.1.1	0	0	19	19
Mechan. Services	1.1.2	0	0	19	19
Safety Systems	1.1.3	0	0	0	0
Preinjector	1.1.4	412	50	104	566
Magnet System	1.1.5	383	43	162	587
Vacuum System	1.1.6	136	66	65	266
RF System	1.1.7	0	0	0	0
I & C System	1.1.8	94	59	76	230
Injection/Ejection	1.1.9	0	0	28	28
Sub Tot Special Facilities	1.1	1,438	256	502	2,197
		0	0	0	0
Techn. Project Mgmt.	1.2.1	59	184	0	243
Administr. Services	1.2.2	16	114	0	129
Sub Tot Project Mgmt./Admi	1.2	75	297	0	372
Sub Tot Base Cost		1,513	554	502	2,569
Project Contingency		254	93	84	431
Total Project (TEC)	1.	1,767	647	587	3,000

M & S, Labor and E D & I by Year (then Year $)

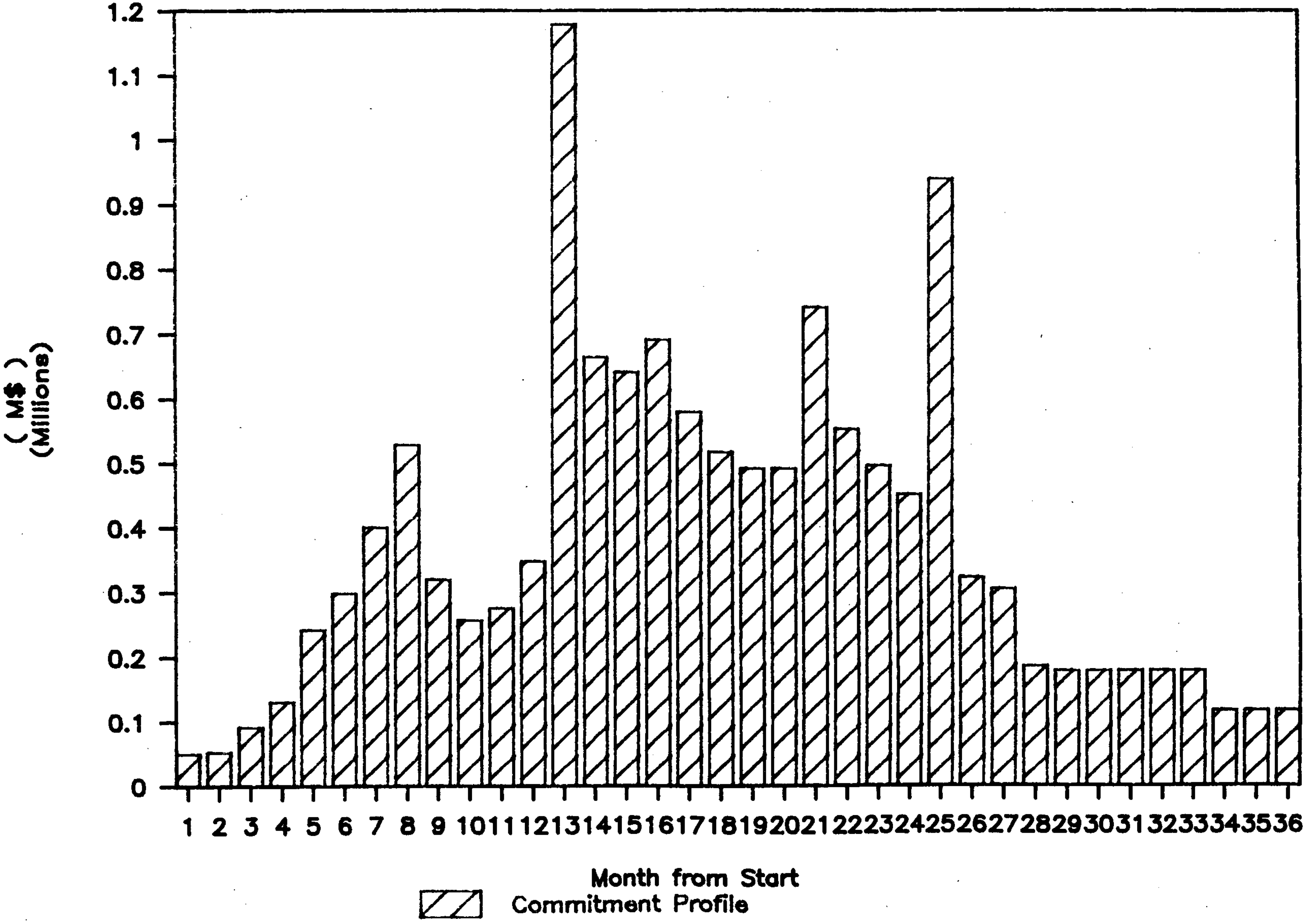
		Escalation Factor:	FY'89	1.117	
Component/Activity	WBS	M&S	Labor	E D & I	Total
Non Tech. Systems	1.1.0	197	23	32	252
Electr. Services	1.1.1	250	113	39	401
Mechan. Services	1.1.2	195	91	39	325
Safety Systems	1.1.3	18	0	0	18
Preinjector	1.1.4	359	130	107	596
Magnet System	1.1.5	982	269	221	1,472
Vacuum System	1.1.6	191	130	90	411
RF System	1.1.7	344	93	206	643
I & C System	1.1.8	383	256	296	934
Injection/Ejection	1.1.9	631	177	118	925
Sub Tot Special Facilities	1.1	3,550	1,280	1,149	5,979
		0	0	0	0
Techn. Project Mgmt.	1.2.1	161	370	0	531
Administr. Services	1.2.2	17	119	0	136
Sub Tot Project Mgmt./Admi	1.2	178	489	0	667
Sub Tot Base Cost		3,727	1,769	1,149	6,645
Project Contingency		479	228	148	855
Total Project (TEC)	1.	4,207	1,997	1,296	7,500

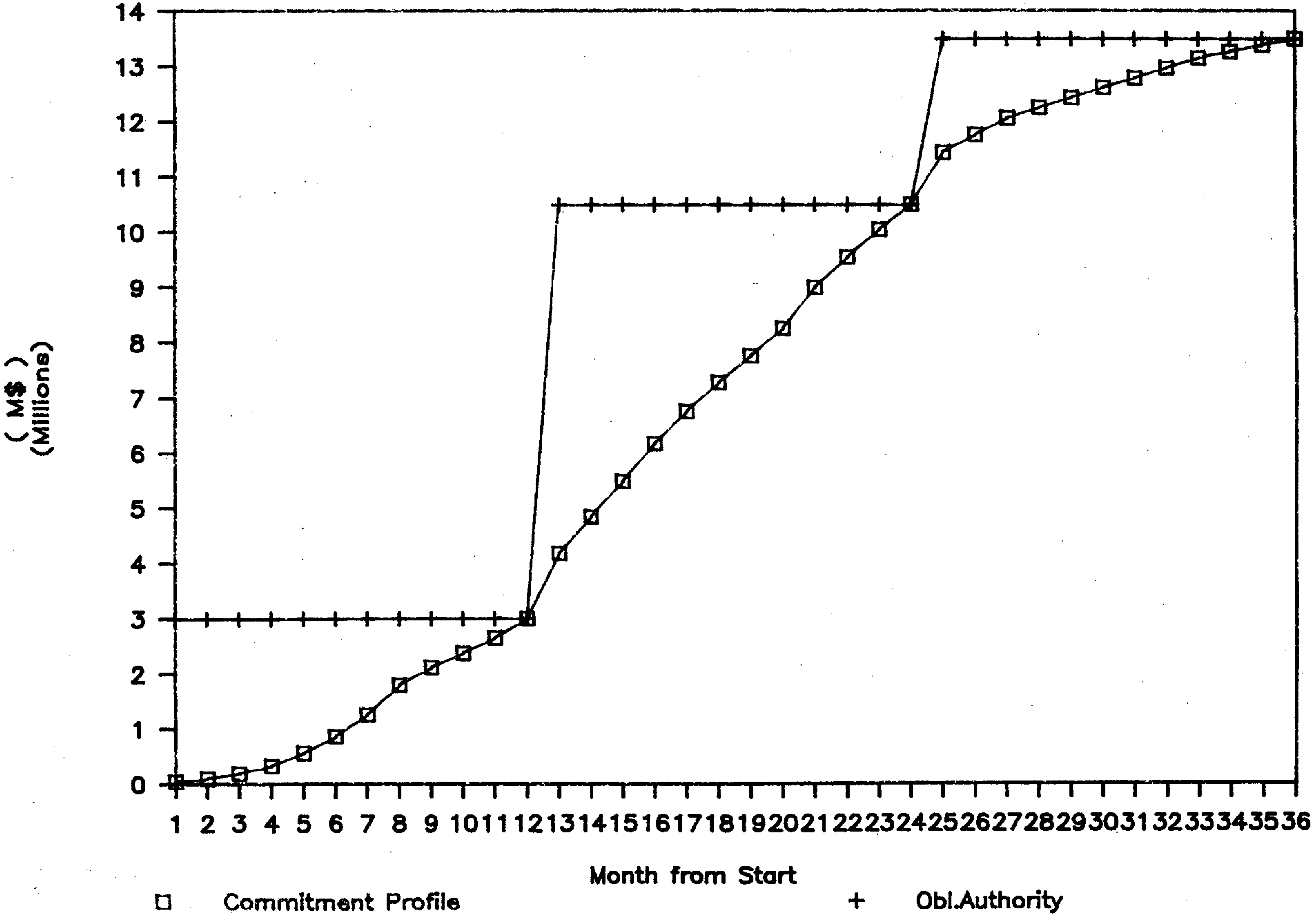
M & S, Labor and E D & I by Year (then Year $)

Component/Activity	WBS	Escalation Factor:	FY'90	1.176	
		M&S	Labor	E D & I	Total
Non Tech. Systems	1.1.0	0	0	0	0
Electr. Services	1.1.1	0	0	0	0
Mechan. Services	1.1.2	0	0	0	0
Safety Systems	1.1.3	5	0	0	5
Preinjector	1.1.4	212	29	25	266
Magnet System	1.1.5	0	0	59	59
Vacuum System	1.1.6	22	0	24	46
RF System	1.1.7	159	0	54	213
I & C System	1.1.8	80	60	50	189
Injection/Ejection	1.1.9	571	209	124	904
Sub Tot Special Facilities	1.1	1,048	297	336	1,682
		0	0	0	0
Techn. Project Mgmt.	1.2.1	111	468	0	579
Administr. Services	1.2.2	17	125	0	143
Sub Tot Project Mgmt./Admi	1.2	128	594	0	722
Sub Tot Base Cost		1,176	891	336	2,403
Project Contingency		292	221	83	597
Total Project (TEC)	1.	1,468	1,112	420	3,000

Commitment Profile

(then Years M$)





Cummulative Commitments

(then Years M$)

Labor Cost Base (FY'86 $)

3 GeV Spear Injector System

ITEM	SLAC CODE	CRAFT CODE	$/MM
CONTRACT SERV. MANAG.	8	AC	11086
FINANCIAL ADMIN.	9	AF	5511
PERSONNEL ADMIN.	10	AP	4589
SECRETARY	5	SE	3324
ADMIN. ASSISTANT		AA	4568
DATA AIDE		DA	2659
ELECTR. COORDINATOR	18	CS	5254
COORDINATOR/PROJECT	2	CP	8513
ALIGNMENT ENGINEER	43	AE	6540
ELECTRICAL ENGINEER	16	EL	6969
MECHANICAL ENGINEER	11	ME	7720
CONSULTANT		CN	7505
MECHANICAL FAB.	27	MF	4525
COMPUTER PROGRAMMER		PR	6390
PROJECT MANAGER		SC	10915
RESEARCH ASSOCIATE		RA	6390
GRAD. STUDENTS (50%)		ST	1598
EXPEDITOR	3	EX	5661
ELECTRON. TECHNICIAN	32	TE	4246
OPERATION TECHNICIAN	42	TO	4589
DOCUMENTATION CLERK		DC	2745
MECHANICAL MACHINING	27	MM	4525
MECHANICAL DESIGNER	52	MD	5487
ELECTRICAL DESIGNER	57	ED	5487
ELECTRICAL ASSEMBLER	63	EA	2732
DAVIS-BACON LABOR		DB	9340
CONTRACT LABOR		JL	3106
UTILITIES/ELECT. T&M		UE	8406
UTILITIES/MECH. T&M		UM	8406
WELDING/VACUUM	79	WV	6491
ELECTRICIAN	84	EL	5207
VACUUM TECHNICIAN	81	TV	6491
MECH. TECHNICIAN	85	TM	6491
ALIGNMENT TECHNICIAN	76	TA	5324
RIGGER	86	RI	5230
ELECTRICAL ENGINEER	66	EE	7635
PLANT ENGINEER	69	CE	7822

MANPOWER DISTRIBUTION

System by WBS:	Rate/MM	Craft Code	Manpower Summary	1.1.0	1.1.1	1.1.2	1.1.3	1.1.4	1.1.5	1.1.6	1.1.7	1.1.8	1.1.9	1.2.1	1.2.2
ADMIN. ASSISTANT	4568	AA	36.00												36.00
CONTRACT SERV. MANAG.	11086	AC	3.00												3.00
ALIGNMENT ENGINEER	6540	AE	0.21						0.21						
FINANCIAL ADMIN.	5511	AF	6.00												6.00
PERSONNEL ADMIN.	4589	AP	9.00												9.00
CIVIL ENGINEER	7822	CE	4.00	4.00											
CONSULTANT	7505	CN	3.00											3.00	
COORDINATOR/PROJECT	8513	CP	12.00											12.00	
COORDINATOR/SYSTEM	5254	CS	64.39					9.00	9.00		12.00	18.00	1.39	15.00	
DATA AIDE	3263	DA	18.00												18.00
DAVIS-BACON LABOR	9340	DB	25.23					1.00	7.73		1.00	6.50	9.00		
DOCUMENTATION CLERK	2745	DC	24.00								6.00	9.00		9.00	
ELECTRICAL ASSEMBLER	2732	EA	0.00												
ELECTRICAL DESIGNER	5487	ED	54.00		4.00			9.00	6.00	2.00	6.00	18.00	6.00	3.00	
ELECTRICAL ENGINEER	7635	EE	100.18		4.00			17.20	9.52	2.00	17.00	33.00	8.46	9.00	
ELECTRICIAN	6969	EL	0.00												
ELECTRONICS ENGINEER	6969	EL	0.00												
EXPEDITOR	5661	EX	0.00												
CONTRACT LABOR	3106	JL	212.76	20.00				16.25	28.68	18.00	24.21	22.01	53.62	30.00	
MECHANICAL DESIGNER	5487	MD	49.00	2.00		4.00		2.00	12.00	12.00	2.00		12.00	3.00	
MECHANICAL ENGINEER	7720	ME	83.86	2.00		4.00		2.92	26.96	16.16	3.00		19.81	9.00	
MECHANICAL FABRICATIO	4525	MF	0.00												
MECHANICAL MACHINING	4525	MM	9.51						3.14	6.37					
COMPUTER PROGRAMMER	6390	PR	18.00									18.00			
RESEARCH ASSOCIATE	6390	RA	12.00											12.00	
RIGGER	5230	RI	10.94	10.94											
PROJECT MANAGER	10915	SC	21.00											21.00	
SECRETARY	3324	SE	0.00												
GRAD. STUDENTS	1598	ST	56.00						2.00					54.00	
ALIGNMENT TECHNICIAN	5324	TA	2.08						2.08						
ELECTRICAL TECHNICIAN	4246	TE	46.71					7.51	12.00		6.50	16.00	4.69		
MECHANCIAL TECHNICIAN	6491	TM	34.88					4.58	15.45				14.86		
OPERATION TECHNICIAN	4589	TO	26.77										2.77	24.00	
VACUUM TECHNICIAN	6491	TV	6.13					0.58					5.55		
UTILITIES/ELECTR. T&M	8406	UE	12.00		12.00										
UTILITIES/MECH. T&M	8406	UM	9.65			9.65									
WELDING/VACUUM	6491	WV	1.43							1.43					
GRAND TOTAL:			971.74	38.94	20.00	17.65	0.00	70.05	134.77	57.96	77.71	140.51	138.16	204.00	72.00

BIG ITEM PROCUREMENT LIST

Item	WBS	Date (+/- 1 month)	Commitment k$
Non Tech. Systems	1.1.0		
Shielding Blocks - I		3/88	100
Shielding Blocks - II		1/89	140
Shelters		6/88	225
Electr. Services	1.1.1		
AC Services incl.Labor		11/88	285
Mechan. Services	1.1.2		
LCW Cooling incl.Labor		11/88	224
Preinjector	1.1.4		
Accel. Sections (2)		4/88	150
Accel. Sect. (Option)		11/89	75
Modulator Components		6/88	100
Klystrons (new)		11/89	105
Magnet System	1.1.5		
Steel/ Laminations		5/88	184
Magnet Coils		11/88	272
Magnet Supports		12/88	105
Magnet Fine Adjustment		9/88	60
Magnet Measurm. Instr.		5/88	30
Power Supplies		12/88	150
Vacuum System	1.1.6		
Vacuum Chambers		6/88	100
Gate Valves		7/89	22
Pumping System		2/89	37
RF System	1.1.7		
RF Klystron (new)		11/89	135
Injection/Ejection	1.1.9		
Magnets/Supports - I		7/89	70
Magnets/Supports - II		11/89	120
Power Supplies - I		8/89	50
Power Supplies - II		11/89	70
Pulsed Magnets - I		3/89	70
Pulsed Magnets - II		7/89	130
Techn. Project Mgmt.	1.2.1		
Fork Lift		1/88	30
Alignment Instruments		1/89	50
Total for Big Procurement List (k$) :			3089

Cost Base for		1.1.0	1.1.1	1.1.2	1.1.3	1.1.4	1.1.5
Engineering Estimate	EU	6.09%		4.57%		12.14%	18.77%
Actual Cost	A	59.38%					21.60%
Vendor Quote	VQ					25.33%	19.41%
Catalog Price	CP					11.46%	0.88%
Similar Project	SP					37.70%	24.20%
SLAC Estimate	SLAC	34.53%	100%	95.43%	100%	11.82%	15.13%
SLC Estimate	SLC					1.55%	
SSRL							

Cost Base for		1.1.6	1.1.7	1.1.8	1.1.9	1.2.1	1.2.2
Engineering Estimate	EU	45.46%	11.93%	11.90%	62.90%	47.14%	83.15%
Actual Cost	A			15.82%	6.73%		
Vendor Quote	VQ		8.76%				
Catalog Price	CP	38.81%		13.42%	1.00%	46.76%	16.85%
Similar Project	SP	4.47%	49.98%	58.86%	18.42%	2.72%	
SLAC Estimate	SLAC		29.34%				
SLC Estimate	SLC	11.26%			10.95%		
SSRL						3.37%	

Cost Base for		Total (K$)	Total (%)
Engineering Estimate	EU	1475	26%
Actual Cost	A	752	13%
Vendor Quote	VQ	504	9%
Catalog Price	CP	458	8%
Similar Project	SP	1365	24%
SLAC Estimate	SLAC	1027	18%
SLC Estimate	SLC	164	3%
SSRL		10	0%
TOTAL MATERIAL COST :		5756	100%

Cost Base for (K$)		1.1.0	1.1.1	1.1.2	1.1.3	1.1.4	1.1.5
Engineering Estimate	EU	34		8		108	232
Actual Cost	A	335					267
Vendor Quote	VQ					225	240
Catalog Price	CP					102	11
Similar Project	SP					335	300
SLAC Estimate	SLAC	195	223	167	20	105	187
SLC Estimate	SLC					14	
SSRL	SSRL						
Total		564	223	175	20	888	1238

Cost Base for (K$)		1.1.6	1.1.7	1.1.8	1.1.9	1.2.1	1.2.2
Engineering Estimate	EU	144	53	59	660	138	37
Actual Cost	A			79	71		
Vendor Quote	VQ		39				
Catalog Price	CP	123		67	10	137	8
Similar Project	SP	14	221	294	193	8	
SLAC Estimate	SLAC		130				
SLC Estimate	SLC	36			115		
SSRL	SSRL					10	
Total		317	443	499	1050	294	45

Cost Base for		TOTAL (K$)
Engineering Estimate	EU	1475
Actual Cost	A	752
Vendor Quote	VQ	504
Catalog Price	CP	458
Similar Project	SP	1365
SLAC Estimate	SLAC	1027
SLC Estimate	SLC	164
SSRL	SSRL	10
TOTAL MATERIAL COST :		5756

Technical Contingency

*** MATERIALS ***	Unit	# of Units	Unit Cost		Total $
30 MW Tube	each	3	35000	SLAC	105000
Klystron	each	1	130000	SLAC	130000
East Pit Injection	Subtotal Magnet System:				170661
	Transport Line PS				36663
	Transport Line Vacuum				40687
only 2 Linac Sections	Modulator (25%) :				74889
	Vacuum System (25%):				10559
Total Materials					568460

*** LABOR ***	# of Units	Units MM	Total MM	Craft Code	Total Labor
East Pit Injection	Subtotal Magnet System (33%):				44804
	Transport Line Vacuum (33%)				18631
	E D & I (33%)				79074
only 2 Linac Sections	Modulator (1):				12513
Total Labor					155022

Total Techn. Contingency	723482

Project Contingency

*** System ***	WBS	Base Cost $	Contingency %	Contingency $
Special Facilities	1.1	8795821	17.0	1494649
Non Techn. Facilities	1.1.0	678683	15.0	101802
Electrical Facilities	1.1.1	376850	15.0	56527
Mechanical Facilities	1.1.2	308859	15.0	46329
Safety Systems	1.1.3	20000	15.0	3000
Preinjector	1.1.4	1291044	15.0	193657
Magnet System	1.1.5	1871995	15.0	280799
Vacuum System	1.1.6	656223	15.0	98433
RF System	1.1.7	756402	10.5	79071
Instrumentaion/Control	1.1.8	1212926	25.0	303232
Injection/Ejection	1.1.9	1622838	20.4	331798
Proj. Mgmt and Admin.	1.2	1606926	11.4	182416
Techn. Management	1.2.1	1242505	12.6	156736
Admin. Services	1.2.2	364421	7.0	25679
Total Project Contingency		10402748	16.1	1677065

1.1.0 Non Technical Systems

1.1.0.0 E D & I

*** LABOR ***	# of Units	Units MM	Total MM	Craft Code	Total Labor
Civil Engineer	1	4	4	CE	31289
Mechanical Engineer	1	2	2	ME	15440
Mechanical Designer	1	2	2	MD	10975
Electrical Engineer	1	0	0	EE	0
Electrical Designer	1	0	0	ED	0
Total Labor					57703
Total 1.1.0.0					57703

1.1.0 Non Technical Systems

1.1.0.1 Site Preparation

*** MATERIALS ***	Unit	# of Units	Unit Cost	Cost Base	Total $
Remove Asphalt/Haul	sq ft	7500	1	SLAC	7500
Excavate for Shelter	c/yd	100	30	SLAC	3000
Excav. for Ring	c/yd	196	30	SLAC	5880
Cable Trench	c/yd	17	30	SLAC	510
Clear Space,Trailer,Crane	lot	1	2000	EU	2000
Total Materials					18890

*** LABOR ***	# of Units	Units MM	Total MM	Craft Code	Total Labor
Clear Space,Trailer,Crane	4.00	1	4	RI	20922
Total Labor					20922
Total 1.1.0.1					39812

1.1.0 Non Technical Systems
1.1.0.2 Shelters
1.1.0.2.1 Booster/Linac Shield.

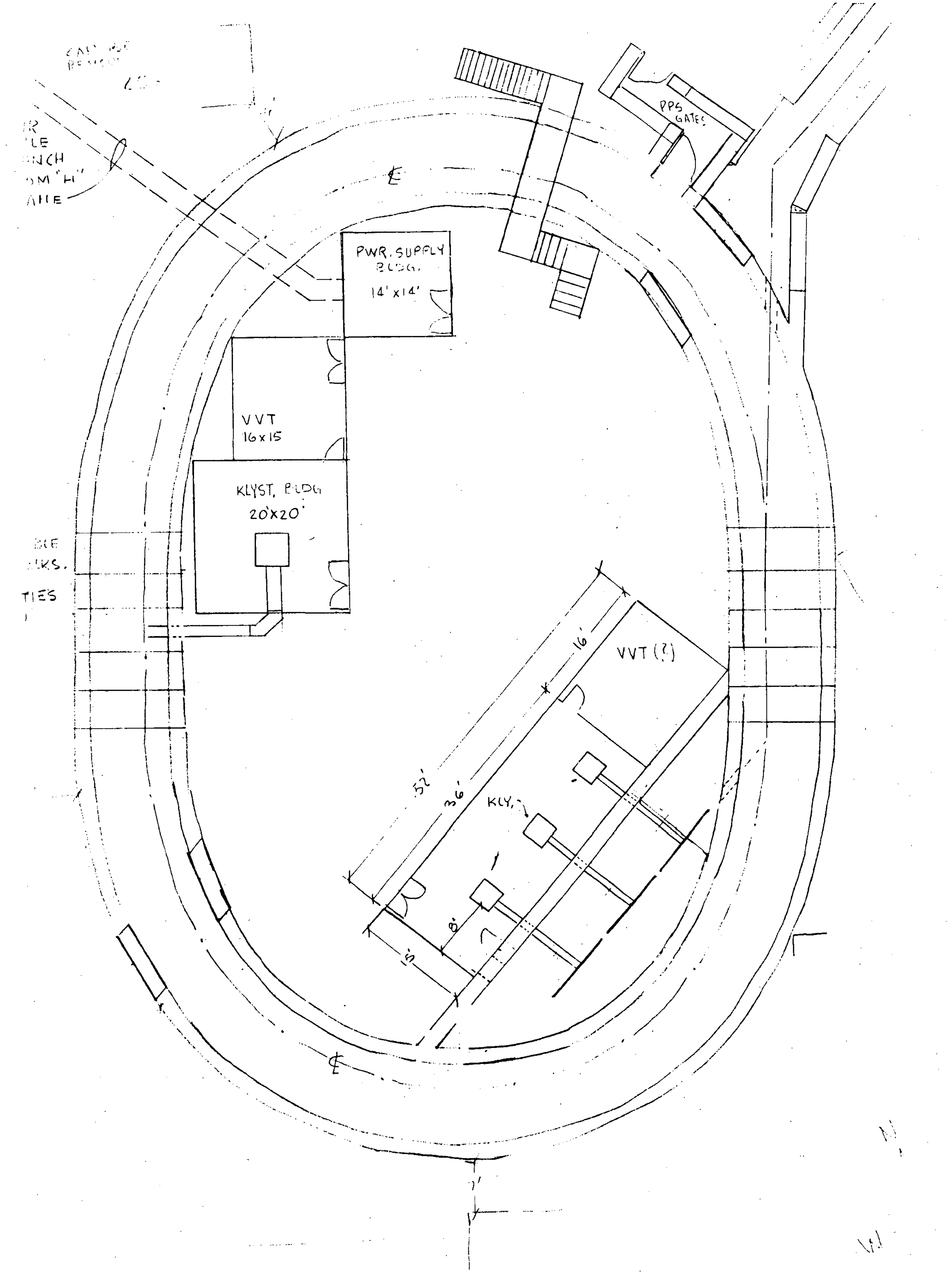
*** MATERIALS ***	Unit	# of Units	Unit Cost	Cost Base	Total $
Concrete/Ring/Floor	c/yd	182	360	A86	65520
Ring Wall	c/yd	395	273	A86	107835
Linac Wall	c/yd	26	273	A86	7098
Roof Blocks	c/yd	171	262	A86	44802
Mazes	c/yd	20	273	A86	5460
Roof over Linac	c/yd	24	262	A86	6288
Drill Holes for Alignment	each	13	100	EU	1300
Drill Holes for Alignment	MM	1	JL	EU	3106
Earthquake Bracing	MM	10	JL	A86	31056
SPEAR Add. Shield. Blocks	c/yd	114	262	A86	29868
Total Materials					302332

*** LABOR ***	# of Units	Units hr	Total MM	Craft Code	Total Labor
Install Shielding Blocks	3	400	6.9	RI	36280
Total Labor					36280
Total 1.1.0.2.1					338612

1.1.0 Non Technical Systems
1.1.0.2 Shelters
1.1.0.2.2 Equipment Shelter

*** MATERIALS ***	Unit	# of Units	Unit Cost	Cost Base	Total $
Ring Klystron	sq ft	400	110	SLAC	44000
VVT Shelter	sq ft	240	110	SLAC	26400
Power Supplies	sq ft	196	110	SLAC	21560
Linac Klystrons	sq ft	540	110	SLAC	59400
VVT for Linac Klystrons	sq ft	240	110	SLAC	26400
misc. Labor	MM	9	JL	EU	27950
Concrete Floor	c/yd	102	360	A86	36846
Total Materials					242556

*** LABOR ***	# of Units	Units MM	Total MM	Craft Code	Total Labor
Total Labor					0
Total 1.1.0.2.2					242556


R
LE
NCH
M "H"
ANE
PPS GATES
℄
PWR. SUPPLY BLDG.
14'x14'
VVT
16x15
KLYST. BLDG
20'x20'
BIE
KS.
TIES
VVT (?)
16'
52'
36'
KLY.
8'
5'
℄
1'
N
W

STANFORD LINEAR ACCELERATOR CENTER

ENGINEER'S ESTIMATE

DATE PREPARED 2-18-86

SUBCONTRACT —

SHEET 1 OF 1

DESCRIPTION CONVENTIAL CONSTR. .3 GEV.

ESTIMATOR AXEL GOLDE

CHK'D BY

DRAWING NO'S —

	ITEM	MATERIAL				LABOR					TOTAL M&L
		UNIT MEAS.	NO. UNITS	UNIT COST	TOTAL	NO. UNITS	UNIT HRS	TOTAL M HRS	$ PER HOUR	TOTAL	TOTAL DIRECT
A	REMOVE ASPHALT & HAUL TO DUMP	SQ/F	6600	$ 1.00	6600						
	EXCAVATE FOR BLDGS	C/YD	100	$ 30.00	3000						
	" " OUTER RING	"	107	"	3235						
	" " INNER RING	"	89	"	2670						
	" CABLE TRENCH	"	17	"	510						
	REMOVE TRAILERS ETC. RIGGERS					MD	20	160	$ 28.00	4480	
B	POUR CONC. FLR. (12") RING	C/YD	188	$590	110920						
	" OUTER RING WALLS	C/YD	189	"	111 510						
	" INNER " "	C/YD	157	"	92630						
	" LINAC WALL	C/YD	34	"	20060						
	" RF. OVER MOST OF RING 12"	C/YD	145	"	85550						
	RF. BLKS	~~EA.~~ C/YD	26	$1000	26000						
	WALL & RF. BLKS OVER MAZES	C/YD	20	$ 1000	20000						
	ADDITIONAL ROOF OVER LINAC	C/YD	28	$ 590	16 520						
	INSTALL (RIGGERS) BLKS etc.					MD	40	320	$28.00	8960	
	BORE "PEEP" HLS. FOR ALIGNMENT	ea.	13	$ 100	1300						
	SUBTOTAL				513945						
	+ CONTINGECIES	%	27		138765						
	TOTAL (A+B) →				652710						

SUBCONTRACT

DESCRIPTION

SHEET OF

SPRL Concrete Floor

excavate
heavy rebar,
profit

drilling conduits
concrete

3200 ft^2 , 1' deep ⇒ 119 yard

Cost : 49 k\$ ⇒ 410 \$/yd

take off excavation
conduits
drilling
} ⇒ 360 \$/yd

FLOOR: 360 \$/yd FY'86

SPRL - SHIELDING WALLS

WALLS	230 yd	$231 524
roof	480 yd	
take off earthquake bracing at $164/yd		-37720
		193804

273 $/yd

Injector:

Outer Wall 371' × 8' × 2' = 5931 ft^3 = 220 yd

Inner Wall 295' × 8' × 2' = 4725 ft^3 = 175 yd

LABOR - DESIGN + FAB

210 CU. YD. TOTAL

DESIGN - 220 HRS X 26.75 = $5885
FAB - ~~480~~ 720 HRS X 17.50 = $8400 + $4200 = $12600
POUR - 336 HRS X 17.50 = $5880
+ HANDLING

SUB-T = $24,365

MATL

FORMS - 10560
CONCRETE - $12,360
REBAR - 1315 + 5541 + 350 = $7206
MISC - OTHER - 146 + 150 + 300 = $596

SUB-T = $30,722

TOTAL = $55,087 -

$262 PER CU. YARD

OVERHEAD SHIELDING BLOCKS

84 BLOCKS @ $656 PER BLOCK

Extra SPEAR SHIELDING

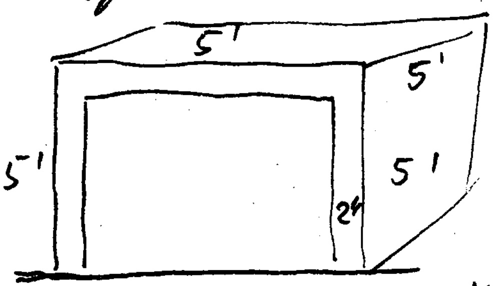
1.) extra 1' over 3/8 of ring.
90 m × 10' wide ⇒ 110 yd.

110 yd × $262 = $28.820

for still more shielding at Septum take existing shielding blocks.

2.) Shielding of Septum:

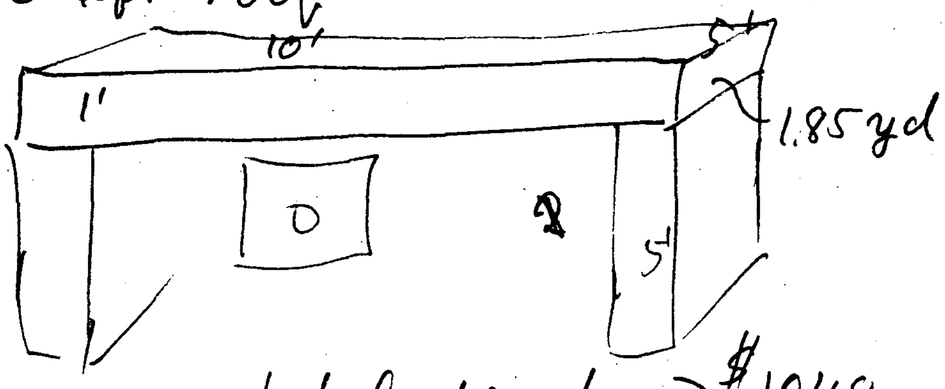
Pb house



675 lead bricks à $25 = $16 875 too expensive

alternative:

Concrete ~~[illegible]~~ roof



total 4 yd → $1048

28820
1048
29868

2-20-87

Ring Tunnel:

walls 2 ft
roof 1 ft

reinforced concr.
blocks SPRC cost
$262/yrd

L_{TUNNEL} = 100 m 300 ft
H_T = 2.5 m 8 ft

Walls: 9600 ft^3 = 355.6 yd

Floor: 16 × 1 × 300 = 4800 ft^3 = 177.8 yd

Roof: 12 × 1 × 300 = 3600 ft^3 = 133.3 yd

$262 / yd reinforced concrete

total yards: 666.7 × 262 = 174.7 k$

assume 6 Blocks / week or 7 ft'/week

↳ 47 weeks to do 100 m

Linac Tunnel 20 m → 10 weeks

} 13 month

1.1.1 Electrical Services
1.1.1.0 E D & I

*** LABOR ***	# of Units	Units MM	Total MM	Craft Code	Total Labor
Electrical Engineer	1	4	4	EE	30542
Electrical Designer	1	4	4	ED	21949
Total Labor					52491
Total 1.1.1.0					52491

1.1.1 Electrical Services

1.1.1.1 AC Services

*** MATERIALS ***	Unit	# of Units	Unit Cost	Cost Base	Total $
12.47 kV Feeder	each	1	46900	SLAC	46900
1000 KVA Transformer	each	1	17000	SLAC	17000
480 V Switch Gear	each	1	25000	SLAC	25000
Metering	set	1	10000	SLAC	10000
AC Distr./Shelters	set	1	33800	SLAC	33800
Light,Outlets Shelter	set	1	10500	SLAC	10500
Light, Outlets Ring	set	1	30800	SLAC	30800
VVT Magnet AC wiring	set	1	5600	SLAC	5600
Magnet Power Distr.	100ft	7	320	SLAC	2112
Misc. Materials	set	1	10000	SLAC	10000
Cable Trays	100ft	21	1550	SLAC	31775
Total Materials					223487

*** LABOR ***	# of Units	Units MM	Total MM	Craft Code	Total Labor
T&M Labor	4.00	3	12	UE	100872
Total Labor					100872
Total 1.1.1.1					324359

STANFORD LINEAR ACCELERATOR CENTER DESIGN DATA	DATE 2-12-86	D.D. NO.	PAGE
SUBJECT SSRL Injector	PREPARED G. DALIT / M. MACHICAO CHECKED BY		

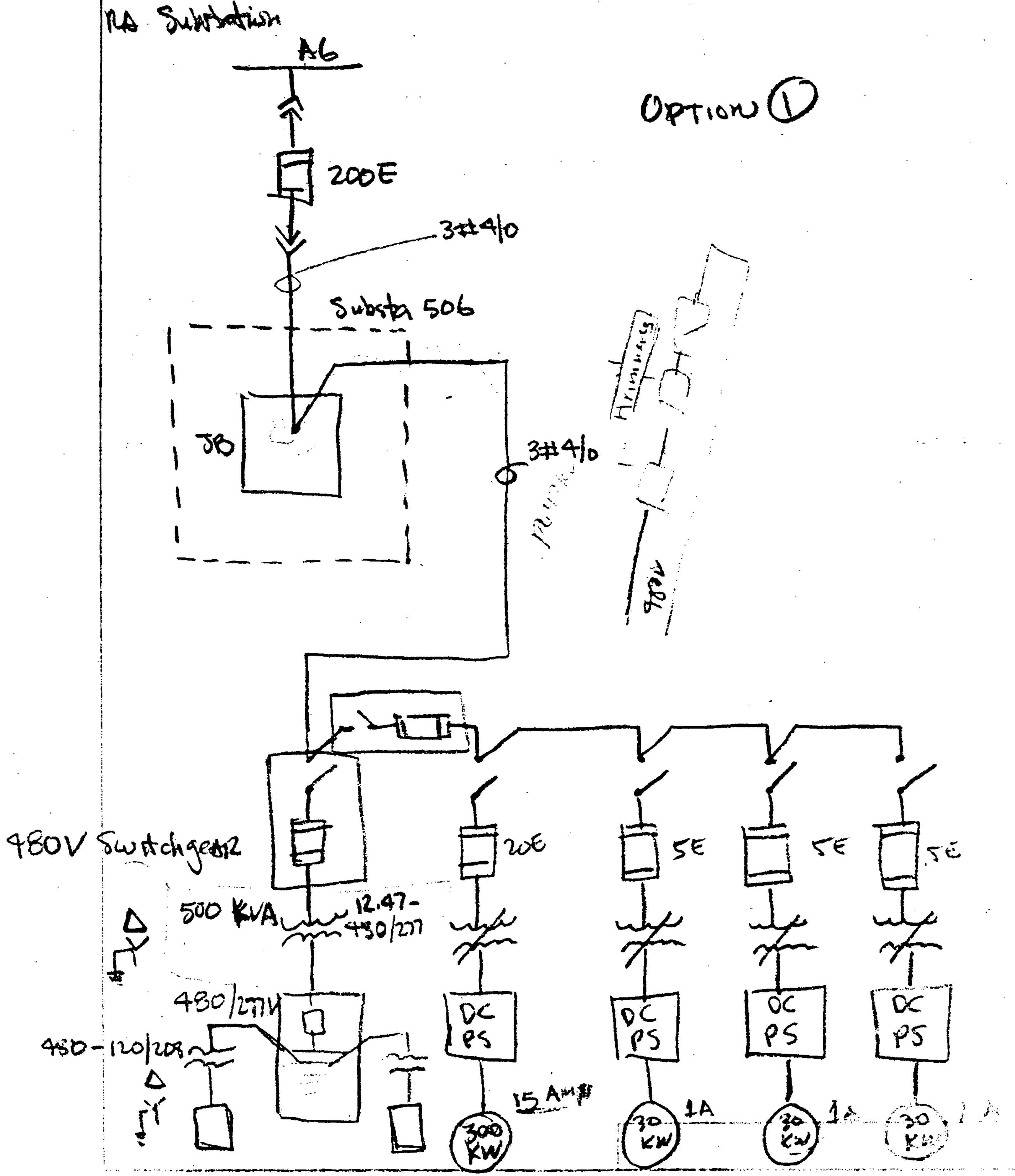
Summary:

FEEDER 12.47KV	$46,900 -	
1000KVA XFMR, 12.47-480Y/277V	20,300	
480V Switchgear @ 1200 Amps Bus	25,000	
Metering	10,000	
Shelters Facility AC Support	44,300	
(Cable Trays 18" w/dividers, 2000'	44,800)	~~I&C~~
Ring AC Support (Lighting, Receptacles, etc)	30,800	
Magnet Power Wiring / VVT Feeders	18,500	
Fire Alarm	20,000	
(COMM/PPS/COMPUTER Cabling	25,000)	I&C
	$285,600	

NOT included
- I&C Cabling
- DC Power Supplies & Cabling
- PPS Gates, MAZE & EQUIPMENT
- EDI

STANFORD LINEAR ACCELERATOR CENTER
DESIGN DATA

DATE	D.D. NO. 1	PAGE
SUBJECT SSRL Injector	PREPARED	
	CHECKED BY	



STANFORD LINEAR ACCELERATOR CENTER
DESIGN DATA

DATE

D.D. NO. 2

PAGE

SUBJECT

SSRL Injector

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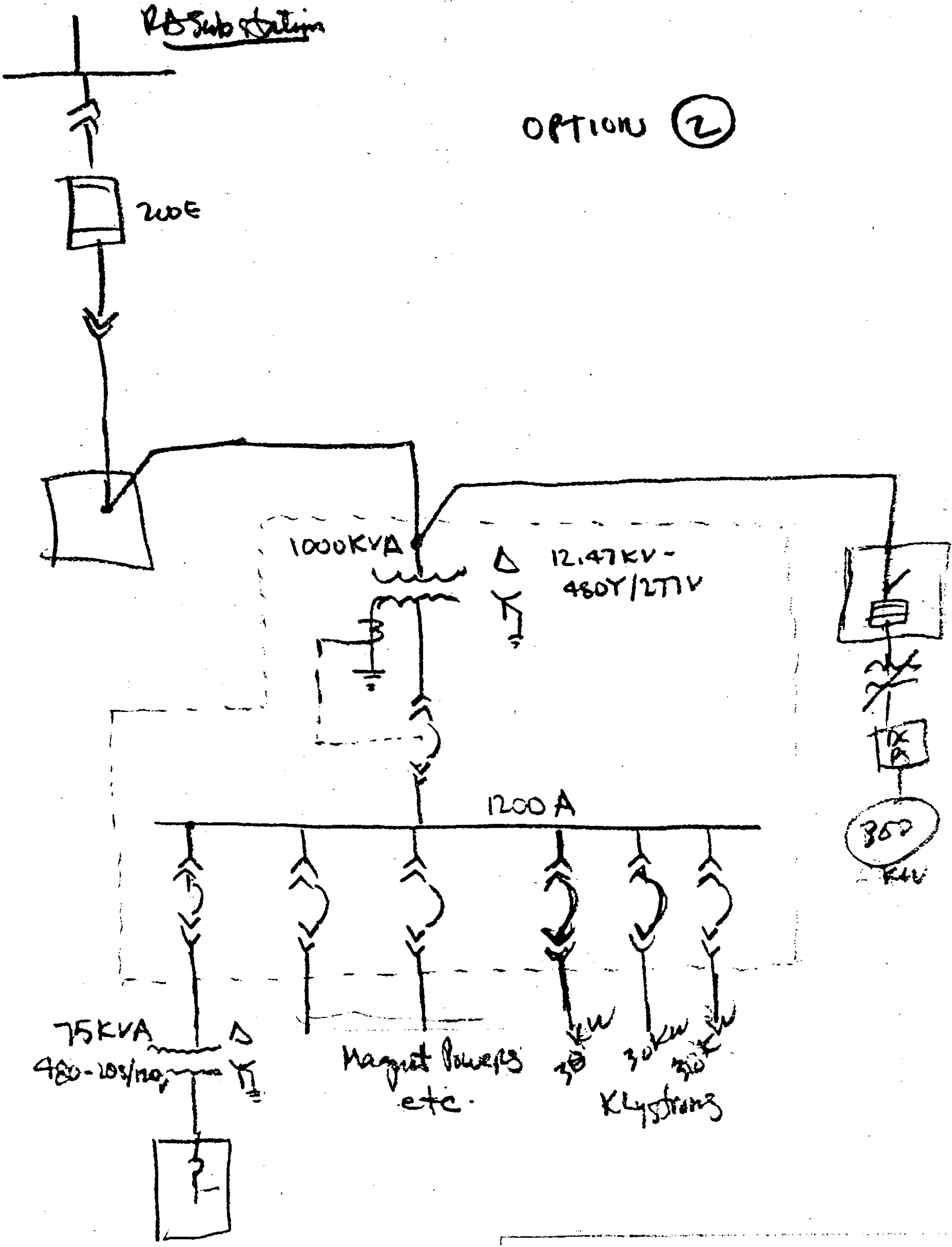

STANFORD LINEAR ACCELERATOR CENTER DESIGN DATA	DATE	D.D. NO.	PAGE
		3	

SUBJECT

PREPARED

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CONVENTIONAL POWER FOR 3 Bldgs

1 - LINAC
1 - 300KW Klystron
1 - 3(30KW) Klystrons

} 480/277 each

120/208 panel each

STANFORD LINEAR ACCELERATOR CENTER DESIGN DATA	DATE	D.D. NO.	PAGE
		4	

SUBJECT

SSRL Injector Ring

PREPARED

CHECKED BY

Cost Estimate:

10,000
19,300
17,600
$ 46,900

Feeder 3 #4/0 PLC 860' x 3" EMT

373/100 = $3208 - $3208

x .16/ft = 137 MHRS 41 x 1.20 = $6740

$9948

$11,01<

450'
x 3
1350'

10'
16"
40"
10"

150
3
450

1,250

10 x 86' ~ ~~860'~~ x 7 = ~~9580'~~ x 1.5 = ~~40000~~ 5800' $
3870

x $3.04/ft 17,500
$3.6 MHR/C x 58 = 209 HRS
x 41 x 1.20
$ 10,300

1 MVA XFRMER - 12.47 - 480Y/277V $17,000

66.67 MHRS x 41 x 1.20 = 3,300

$20,300

480V Switchgear - @ 1200 Amps / 480V - $ 14,150

x 1.20

28 30.00

Labor & material $ 17,150

Duct Bank 100' x $50/ft = $3500

Asphalt 100' x 25 = 2,500

100 x 2 = 200

$ 6,000

Shelters 40 x 20 = 800' x 2 = 1600 ft²

20 x 20 = 400' 2 400 ft²

80

2000 ft²

Lunge + 30kw (3)
300 kw

perimeter = 320 ft ~ 500'

x 7.25

$ 3,625.00 Grounding

Distribution : 277/480V - 3 x $4400 = $13,200

panels 120/208 - 3 x $2400 = 7,200

Branch circuits : 1.06 x 2000 ft² = 2,500

$ 22,900

Lighting $4.50 x 2000 ft² = $ 9000

Outlets $ .75 x 2000 ft² = $ 1000

STANFORD LINEAR ACCELERATOR CENTER
DESIGN DATA

DATE
D.D. NO. 1
PAGE 8

SUBJECT

PREPARED

CHECKED BY

Xformers 3 @ $2700 = $7,100 480-120/208

Shelters facility DC support:

$7,100	XFMRS
$3,700	Grounding
23,000	Distribution Power
9,000	Lighting
1,500	Outlets
$44,300.	

480V Switchgears @ 1200 Amp Bus $25,000
w/ Breakers $1800 × 4 = $4,800
$17,200
4,800
$22,000

Metering $10,000
$1700
3500
1700
2,150
$9,050 $10,000

1000 KVA XFMR : $17,000 $20,300
67×41×1,20 = 3,300 labor
$20,300

Cable trays 18" w/ divider, 2000' $44,800

Ring: Lighting 33 fixtures 2-4' @ 135/ea $4500
33 incandescent @ 75/ea 2500
$7000
Receptacles 65 duplex @ 17/ea $1300 $8,300
$8,300
every 10', quad box
Wires: 2-quads/Ckt 15 Ckts @ 120V 228/2 = 175'
4 fixtures/ckt 10 Ckts @ 120V
25 Ckts
4
#10 THHN $350
3/4" CNT 945
$1745
$2,000

Subtotal $139,600

STANFORD LINEAR ACCELERATOR CENTER DESIGN DATA	DATE	D.D. NO.	PAGE
		2	B

SUBJECT

PREPARED

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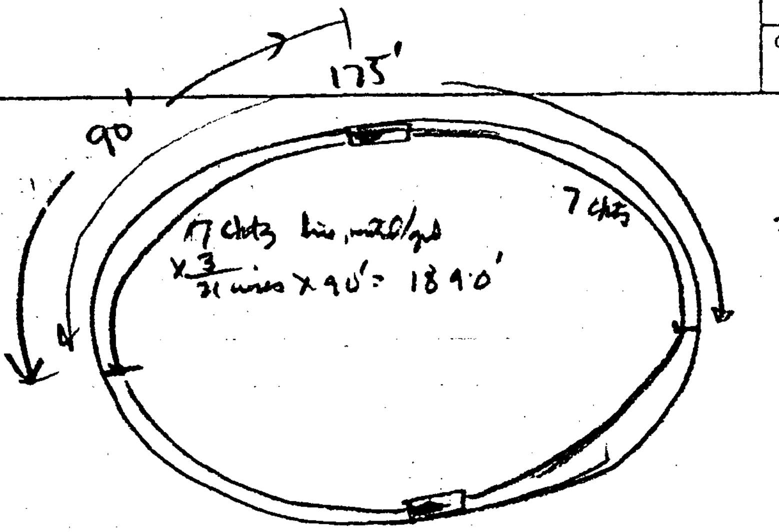


Say 2000' per 1/4 of ring

		Material	Labor
x 4 8000' #10 THHN WIRE ($96/1000)	= $800	.8/100	64 MHRS $ 10,650
4 25 ckt x 90', EMT 3/4" ($42/100) 2250' .062MH/F	= $ 945 1745		$ 7,000
2 - 75KVA x $2700	$ 5,400		
2 - 42Amp 120/208x - $3000	$ 6,000		
	$ 31,000		

FireAlarm : $ 15,000

Comm/PPS/Computer : $ 25,000

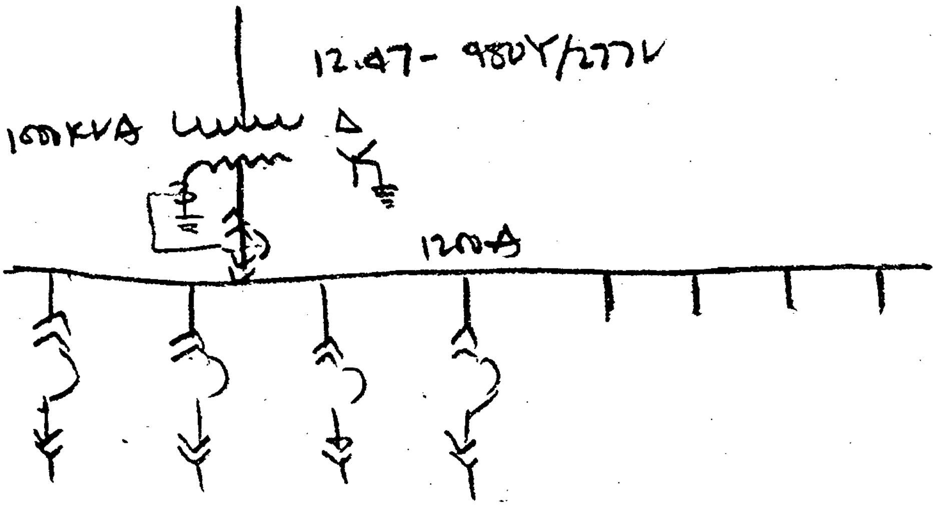
11,400
15,000
12,000
$ 38,400

	Mat	Labor
Magnet Power per side - 3 ckts x 328' x 5 = 1620 3 4860' $96/1000 .8/100	= $452	2000
EMT' 3 x 328 = 984 x 1.5 4920 984 3/4" - 1476' - $42/100 .06/FT - [illegible]	$ 600	4400
	2 x $7452	
	both sides	
	= $14,904	

STANFORD LINEAR ACCELERATOR CENTER
DESIGN DATA

SUBJECT	DATE	D.D. NO. 3	PAGE B
	PREPARED		
	CHECKED BY		

① 480V SWITCH GEAR



$$\frac{1\,\text{MVA}}{12.47\,\text{KV} \times 1.732} = I$$

$$24\Big)\frac{\overset{50}{1000\,\cancel{\text{KVA}}}}{12.47 \times 1.732\,\cancel{\text{K}}} =$$

$$\frac{1000\ \text{KVA}}{480 \times 1.73\ \text{K}}$$

558

② Cable trays

control to Ring $5 \times 12 \times 10'' = 600'$ Say $1000'$

Ring $328'$

$600 + 328 = 928$

$1000 + 950 = 1950'$ use $\boxed{2050'}$

wide 18" w/dividers $2.65/ft

Say 2050' x $15.50 = $31,000

$$\frac{\begin{array}{r}31{,}000\\ 6{,}360\end{array}}{\$\,37{,}360} \times 1.20 = \$44{,}8[illegible]$$

STANFORD LINEAR ACCELERATOR CENTER DESIGN DATA	DATE	D.D. NO. 4	PAGE B
SUBJECT	PREPARED		
	CHECKED BY		

@ 480V @ 12.47KV
30KW 300KW (8'x10'= 80')

VVT Connections: 36 Amps (10') 313 Amps

Install Breaker 8hrs x41x1.20 = $400 10 hrs x 4x41x1.20 = $500
Conduit 3/4" 10' = 94/100 42 $5 30 2" 80' 2.42/c = $298
Wire 4 #10 - 40' = 94/100 1 = 38 41 4-1/0 #320', 1.31 = $104
Terminate 4hrs x41x1.20 = 200 8hrs $90

709
15% Fittings/Labr 106
$805
x 3
815

3.2 x 2.42 = 7.74
$381
320 x 1.7 = $544
$2027
x1.15
2331

Total: $815
$2331
$3146

VVT + Magnet AC : $ 3,500
15,000
$ 18,500

Cable Trays:

Ring two trays à 300 ft =	600 ft
VVT - Shelter	100 ft
Klystron Shelter	200 ft
PS - Shelter	400 ft
LINAC Housing 3 trays à 50 ft	150 ft
LINAC Modulators 5 trays à 50 ft	250 ft
Booster - SPEAR Transport Line	100 ft
Cross Connect (Shelters - Linac) 3 trays à 100 ft	300 ft
	2100 ft

Labor: $/foot

1.1.2 Mechanical Services

1.1.2.0 E D & I

*** LABOR ***	# of Units	Units MM	Total MM	Craft Code	Total Labor
Mechanical Engineer	1	4	4	ME	30879
Mechanical Designer	1	4	4	MD	21949
Total Labor					52828
Total 1.1.2.0					52828

1.1.2 Mechanical Services
1.1.2.1 LCW Cooling System

*** MATERIALS ***	Unit	# of Units	Unit Cost	Cost Base	Total $
400 GPM - 6'' SS	ft	250	20	SLAC	5000
6' Block Valves	each	4	800	SLAC	3200
6' Flanges	each	10	220	SLAC	2200
90 Degree Elbows 6'	each	12	120	SLAC	1440
Orifice Flange	each	1	600	SLAC	600
Supports/Hangers	each	100	12	SLAC	1200
Klystrons Pipe/Inst	each	1	6000	SLAC	6000
Linac Kly. Pipe/Inst	each	3	1150	SLAC	3450
Linac Cooling Pipe	each	3	1500	SLAC	4500
Linc Cool. Temp. Con	each	1	35000	SLAC	35000
Booster Cool. Piping	each	1	4500	SLAC	4500
Booster Cool. Temp. C	each	1	15000	SLAC	15000
Cavity Cool. Pipes	each	1	1600	SLAC	1600
Magnet Cooling Pipes	system	12	1000	SLAC	12000
Wave guide Cooling	system	3	1000	SLAC	3000
Compressed Air	system	1	600	SLAC	600
SUB TOTAL					99290
Contr. Overhead/Profit	%	25		SLAC	45097
General Contractor	%	10		SLAC	22548
Misc. Material				EU	8000
Total Materials					174935

1.1.2 Mechanical Services (con't)

1.1.2.1 LCW Cooling System

*** LABOR ***	# of Units	Units hr	Total MM	Craft Code	Total Labor
400 GPM - 6'' SS	250	0.30	0.43	UM	3644
6' Block Valves	4	3	0.07	UM	583
6' Flanges	10	8	0.46	UM	3887
90 Degree Elbows 6'	12	6	0.42	UM	3498
Orifice Flange	2	8	0.09	UM	777
Supports/Hangers	12	4	0.28	UM	2332
6' SS Welds	60	6	2.08	UM	17492
Klystrons Pipe/Inst	1	60	0.35	UM	2915
Linac Kly. Pipe/Inst	3	12	0.21	UM	1749
Linac Cooling Pipe	3	30	0.52	UM	4373
Linac Cool. Temp. Con	1	300	1.73	UM	14577
Booster Cool. Piping	1	80	0.46	UM	3887
Booster Cool. Temp. C	1	100	0.58	UM	4859
Cavity Cool. Pipes	1	60	0.35	UM	2915
Magnet Cooling Pipes	12	16	1.11	UM	9329
Wave Guide Cooling	3	16	0.28	UM	2332
Compressed Air	1	40	0.23	UM	1944
Total Labor					81096
Total 1.1.2					256031

PROPOSED SSRL SPEAR INJECTOR H. Weidemann #69 Bill

STANFORD LINEAR ACCELERATOR CENTER

ENGINEER'S ESTIMATE

DATE PREPARED 2-13-86

SUBCONTRACT

SHEET 1 OF 1

DESCRIPTION SSRL-COOLING WATER FACILITIES FOR PROPOSED ELECTRON FAC.

ESTIMATOR DBR

CHK'D BY

DRAWING NO'S

ITEM	MATERIAL				LABOR					TOTAL M&L
	UNIT MEAS.	NO. UNITS	UNIT COST	TOTAL	NO. UNITS	UNIT HRS	TOTAL M HRS	$ PER HOUR	TOTAL	TOTAL DIRECT
ASSUME LCW FROM ESA										
400 GPM-6" SS	LIN FT	250	20.00	5000	250	0.3	75	45	3375	
6" BLOCK VALVES	EA	4	800	3200	4	3	12	45	540	
6" FLANGES	EA	10	220	2200	10	8	80	45	3600	
70° ELBOWS 6"	EA	12	120	1440	12	6	72	45	3240	
ORIFICE FLANGES	EA	1 SET	600	600	2	8	16	45	720	
SUPPORTS & HANGERS	EA	100	12	1200	12	4	48	45	2160	
6" SS WELDS	EA	60	—	—	60	6	360	45	16,200	
PEP TYPE KLYSTRON PIPE & INST.	EA	1	6,000	6,000	1	60	60	45	2700	
ACCEL TYPE KLYSTRON PIPE & INST.	EA	3	1150	1450	3	12	36	45	1620	
ACCEL. COOLING PIPING	EA	3	1500	4500	3	30	90	45	4050	
ACCEL. COOL. TEMP. CONTROL	EA	1	SYSTEM	35,000	1	300	300	45	12,500	
INJECTOR COOLING PIPING	EA	1	4500	4500	1	80	80	45	3,600	
INJECTOR TEMP CONTROL	EA	1	SYSTEM	15,000	1	100	100	45	4,500	
R.F. CAVITY PIPING	EA	1	1000	1,600	1	60	60	45	2,700	
QUAD & MAGNET COOLING	SYSTEM	12	1000	12,000	12	16	192	45	8360	
WAVE-GUIDE COOLING	SYSTEM	3	1000	3,000	3	16	48	45	2160	
COMPRESSED AIR	SYSTEM	1	600	600	1	40	40	45	2250	
				97290					74,275	171,565
ASSUME MECH. CONTRACTOR OVHD & PROFIT @ 10% +					5%					45,465
										217,030
ASSUME GENERAL CONTRACTOR MARK-UP @ 10%										21,700
										238,730

SUBCONTRACT

DESCRIPTION

SHEET OF

1.1.3 Safety Systems

1.1.3.1 Fire Safety

*** MATERIALS ***	Unit	# of Units	Unit Cost	Cost Base	Total $
Fire Alarm	System	1	20000	SLAC	20000
Total Materials					20000

*** LABOR ***	# of Units	Units MM	Total MM	Craft Code	Total Labor
Fire Alarm					
Total Labor					0
Total 1.1.3.1					20000

1.1.4 LINEAR ACCELERATOR SYSTEMS

1.1.4.0 E D & I

*** LABOR ***	# of Units	Units MM	Total MM	Craft Code	Total Labor
Electr. Engineering	1	12	12	EE	91625
Mech. Engineering	1	2	2	ME	15440
Mechanical Designer	1	2	2	MD	10975
Electrical Designer	1	9	9	ED	49385
Coordinator	1	9	9	CS	47284
Total Labor					214709
Total 1.1.4.0					214709

1.1.4 LINEAR ACCELERATOR SYSTEMS

1.1.4.1 Gun Assembly

1.1.4.1.1 Cathode Assembly

*** MATERIALS ***	Unit	# of Units	Unit Cost	Cost Base	Total $
Cathode/Heater	each	1	600	SP84	600
Power Supply	each	1	300	SP84	300
LaB6 Crystal	each	1	1000	SP84	1000
Box Car	each	1	3000	SP84	3000
Feedback Electronics	each	1	2500	SP84	2500
Contract Labor	hr	160	JL	SP84	2872
Total Materials					10272

*** LABOR ***	# of Units	Units hr	Total hr	Craft Code	Total Labor
	1	120	120	EE	5296
	1	120	120	TE	2945
Total Labor					8241
Total 1.1.4.1.1					18514

1.1.4 LINEAR ACCELERATOR SYSTEMS

1.1.4.1 Gun Assembly

1.1.4.1.2 RF/Cavity Assembly

*** MATERIALS ***	Unit	# of Units	Unit Cost	Cost Base	Total $
Splitter	set	1	1500	EU	1500
Attenuator	each	1	4500	EU	4500
Phase Shifter	each	1	4000	EU	4000
Circulator	each	1	1500	CP	1500
Wave Guides	set	1	2000	SP84	2000
Cavity	each	1	2500	SP84	2500
Temp. Stability	set	1	1000	SP84	1000
Electronics	set	1	1000	SP84	1000
RF Window	each	1	2000	SP84	2000
Chopper Deflector	each	1	7500	EU	7500
Chopper Pulser	set	1	5000	EU	5000
Contract Labor	hr	400	JL	EU	7180
Total Materials					39680

*** LABOR ***	# of Units	Units hr	Total M Hrs	Craft Code	Total Labor
	1	120	120	EE	5296
	1	240	240	TE	5890
	1	240	240	TM	9005
Total Labor					20192
Total 1.1.4.1.2					59872

1.1.4 LINEAR ACCELERATOR SYSTEMS

1.1.4.1 Gun Assembly

1.1.4.1.3 Beam Guidance

*** MATERIALS ***	Unit	# of Units	Unit Cost	Cost Base	Total $
Quadrupoles	each	6	500	SP84	3000
Steering Magnets	each	6	300	SP84	1800
Power Supplies	each	12	800	SP84	9600
Cabling	lot	1	1500	EU	1500
Chopper DC Deflector	each	1	400	EU	400
Slit Assembly	each	1	1000	SP84	1000
Contract Labor	hr	120	JL	SP84	2154
Total Materials					19454

*** LABOR ***	# of Units	Units hr	Total M Hrs	Craft Code	Total Labor
	1	40	40	ME	1785
	1	40	40	TM	1501
	1	40	40	EE	1765
Total Labor					5051
Total 1.1.4.1.3					24505

1.1.4 LINEAR ACCELERATOR SYSTEMS

1.1.4.1 Gun Assembly

1.1.4.1.4 Momentum Filter

*** MATERIALS ***	Unit	# of Units	Unit Cost	Cost Base	Total $
Core	each	1	800	SP84	800
Coils	each	1	1000	SP84	1000
Momentum Filter	each	1	1500	SP84	1500
Support	each	1	1500	SP84	1500
Power Supply	each	1	1600	SP86	1600
Contract Labor	hr	80	JL	SP84	1436
Total Materials					7836

*** LABOR ***	# of Units	Units hr	Total M Hrs	Craft Code	Total Labor
	1.00	40	40	ME	1785
	1.00	80	80	TM	3002
Total Labor					4787
Total 1.1.4.1.4					12623

1.1.4 Linear Accelerator Systems
1.1.4.1 Gun Assembly
1.1.4.1.5 Diagnostics

*** MATERIALS ***	Unit	# of Units	Unit Cost	Cost Base	Total $
Profile Monitor/Instrum.	each	1	1350	SLC	1350
Gap Monitor/Instrum.	each	1	1060	SLC	1060
Faraday Cup/Instrum.	each	1	2680	SLC	2680
Profile Monitor/Electr.	each	1	6300	SLC	6300
Gap Monitor/Electronics	each	1	1200	SP86	1200
Faraday Cup/Electronics	each	1	2200	SP86	2200
Contract Labor/Instrum.	hr	130	JL	SLC	2334
Contract Labor/Electr.	hr	80	JL	SP86	1436
Total Materials					18560

*** LABOR ***	# of Units	Units hr	Total M Hrs	Craft Code	Total Labor
	1.00	40	40	EE	1765
	1.00	40	40	TE	982
Total Labor					2747
Total 1.1.4.1.5					21307

1.1.4 LINEAR ACCELERATOR SYSTEMS

1.1.4.1 Gun Assembly

1.1.4.1.6 Vacuum System

*** MATERIALS ***	Unit	# of Units	Unit Cost	Cost Base	Total $
Turbo Pump	each	1	1000	CP	1000
Hand Valve	each	1	800	CP	800
Gate Valve	each	1	1200	CP	1200
Ion Pumps	each	3	1350	CP	4050
Ion Pump PS	each	1	1600	CP	1600
Gauges	each	3	319	CP	957
Misc. Pipes/Flanges/Bolts	lot	1	3500	EU	3500
Ion Gauge Controller	each	3	875	CP	2625
Contract Labor	hr	100	JL	EU	1795
Total Materials					17527

*** LABOR ***	# of Units	Units hr	Total M Hrs	Craft Code	Total Labor
	1.00	40	40	ME	1785
	1.00	60	60	TV	2251
Total Labor					4036
Total 1.1.4.1.6					21563

1.1.4 LINEAR ACCELERATOR SYSTEMS

1.1.4.2 Acceleration Sections

*** MATERIALS ***	Unit	# of Units	Unit Cost	Cost Base	Total $
Sections	each	3	75000	VQ85	225000
Support	m	9	1800	SP86	16200
Misc. Materials	lot	1	3000	EU	3000
Contract Labor	hr	120	JL	EU	2154
Total Materials					246354

*** LABOR ***	# of Units	Units hr	Total M Hrs	Craft Code	Total Labor
	3.00	20	60	EE	2648
	3.00	64	192	TM	7204
Installation	1.00	173	173	DB	9340
Total Labor					19192

Total 1.1.4.2	265546

1.1.4 LINEAR ACCELERATOR SYSTEMS

1.1.4.3 Modulators

*** MATERIALS ***	Unit	# of Units	Unit Cost	Total $
1.1.4.3.1 HV Power Supply	each	3	19649	58947
1.1.4.3.2 Pulse Form. Net	each	3	42806	128419
1.1.4.3.3 Controls	each	3	12434	37302
Total Modulators				224667

*** LABOR ***	# of Units	Unit Cost	
1.1.4.3.1 HV Power Supply	3.00	7656	22967
1.1.4.3.2 Pulse Form. Net	3.00	9421	28263
1.1.4.3.3 Controls	3.00	7949	23846
Total 3 Modulators			75076
Total 1.1.4.3			299743

1.1.4 LINEAR ACCELERATOR SYSTEMS

1.1.4.3.1. HV Power Supply (3)

*** MATERIALS ***	Unit	# of Units	Unit Cost	Cost Base	Total $
Variac	set	1	5000	SP86	5000
Power X-former	set	1	3000	SP86	3000
Oil and/or SF6	lot	1	500	SP86	500
Cabinet for PS and Modul.	each	1	10000	SP86	10000
Contract Labor	hr	64	JL	SP86	1149
Total Materials	3 units				58947

*** LABOR ***	# of Units	Units hr	Total M Hrs	Craft Code	Total Labor
	1.00	40	40	EE	1765
	1.00	240	240	TE	5890
Total Labor	3 units				22967

Total 1.1.4.3.1	3 units	81914

1.1.4 LINEAR ACCELERATOR SYSTEMS

1.1.4.3.2 PFN

*** MATERIALS ***	Unit	# of Units	Unit Cost	Cost Base	Total $
Contract Labor	hr	485	JL	SP86	8706
Diodes	set	1	1200	SP86	1200
Relays	each	2	250	SP86	500
Fuses	each	4	100	SP86	400
Toroids	each	3	100	SP86	300
Filter Choke	each	1	1500	SP86	1500
Capacitors	set	1	6000	SP86	6000
Charging Choke	each	1	1500	SP86	1500
PFN Coils	each	1	500	SP86	500
EOL Network	each	1	2000	SP86	2000
Thyratron	each	1	18000	CP	18000
Thyratron/PS	each	1	2000	SP86	2000
Voltage Divider	each	1	200	SP86	200
Total Materials (3)	3 units				128419

*** LABOR ***	# of Units	Units hr	Total M Hrs	Craft Code	Total Labor
	1.00	80	80	EE	3531
	1.00	240	240	TE	5890
Total Labor	3 units				28263
Total 1.1.4.3.2	3 units				156682

1.1.4 LINEAR ACCELERATOR SYSTEMS

1.1.4.3.3 Controls

*** MATERIALS ***	Unit	# of Units	Unit Cost	Cost Base	Total $
PFN Charging Signal	each	1	200	SP86	200
Microprocessor	each	1	1000	SP86	1000
Electronic Box	each	1	1000	SP86	1000
Bias Power Supply	each	1	500	SP86	500
Filament Power Supply	each	1	1000	SP86	1000
Trigger Box	each	3	1000	SP86	3000
Electronics Rack	each	1	2000	SP86	2000
Contract Labor	hr	208	JL	SP86	3734
Total Materials	3 units				37302

*** LABOR ***	# of Units	Units hr	Total M Hrs	Craft Code	Total Labor
	1.00	80	80	EE	3531
	1.00	180	180	TE	4418
Total Labor	3 units				23846

Total 1.1.4.3.3	3 units	61147

1.1.4 LINEAR ACCELERATOR SYSTEMS

1.1.4.4 Klystrons

*** MATERIALS ***	Unit	# of Units	Unit Cost	Cost Base	Total $
30 MW Tube	each	1	35000	SLAC	35000
Focusing from SLAC	each	1	0		0
Tank/Cable from SLAC	each	1	1000	EU	1000
Misc. Materials	lot	1	500	EU	500
Waveguides	set	1	3000	EU	3000
Supports	each	1	1500	EU	1500
Waveguides/Assembly	hr	24	JL	EU	431
Contract Labor	hr	80	JL	EU	1436
Total Materials	3 units				128601

*** LABOR ***	# of Units	Units hr	Total M Hrs	Craft Code	Total Labor
	3.00	40	120	EE	5296
	3.00	40	120	TE	2945
Total Labor	3 units				24724
Total 1.1.4.4					153325

1.1.4 LINEAR ACCELERATOR SYSTEMS

1.1.4.5 Controls

*** MATERIALS ***	Unit	# of Units	Unit Cost	Cost Base	Total $
RF Drive(TWT with PS)	each	1	50000	SP86	50000
Timing System	each	1	20000	SP86	20000
Diagnostics	set	1	2000	SP86	2000
S-Band Master Oscillator	each	1	12000	SP86	12000
Contract Labor	hr	240	JL	EU	4308
Total Materials					88308

*** LABOR ***	# of Units	Units hr	Total M Hrs	Craft Code	Total Labor
	1.00	80	80	EE	3531
	1.00	120	120	TE	2945
Total Labor					6476
Total 1.1.4.5					94784

1.1.4 LINEAR ACCELERATOR SYSTEMS

1.1.4.6 Vacuum

*** MATERIALS ***	Unit	# of Units	Unit Cost	Cost Base	Total $
Ion Pumps	each	3	1350	CP	4050
Ion Pump Supplies	each	3	1600	CP	4800
Misc. Valves	set	1	1000	EU	1000
Pressure Monitoring	set	4	1338	CP	5352
Roughing System	set	3	4253	CP	12759
Mobile Roughing System	each	1	2320	CP	2320
misc. Pipes/Flanges/Bolts	lot	1	2300	EU	2300
BPM's	each	6	1250	SP86	7500
Contract labor	hr	120	JL	EU	2154
Total Materials					42235

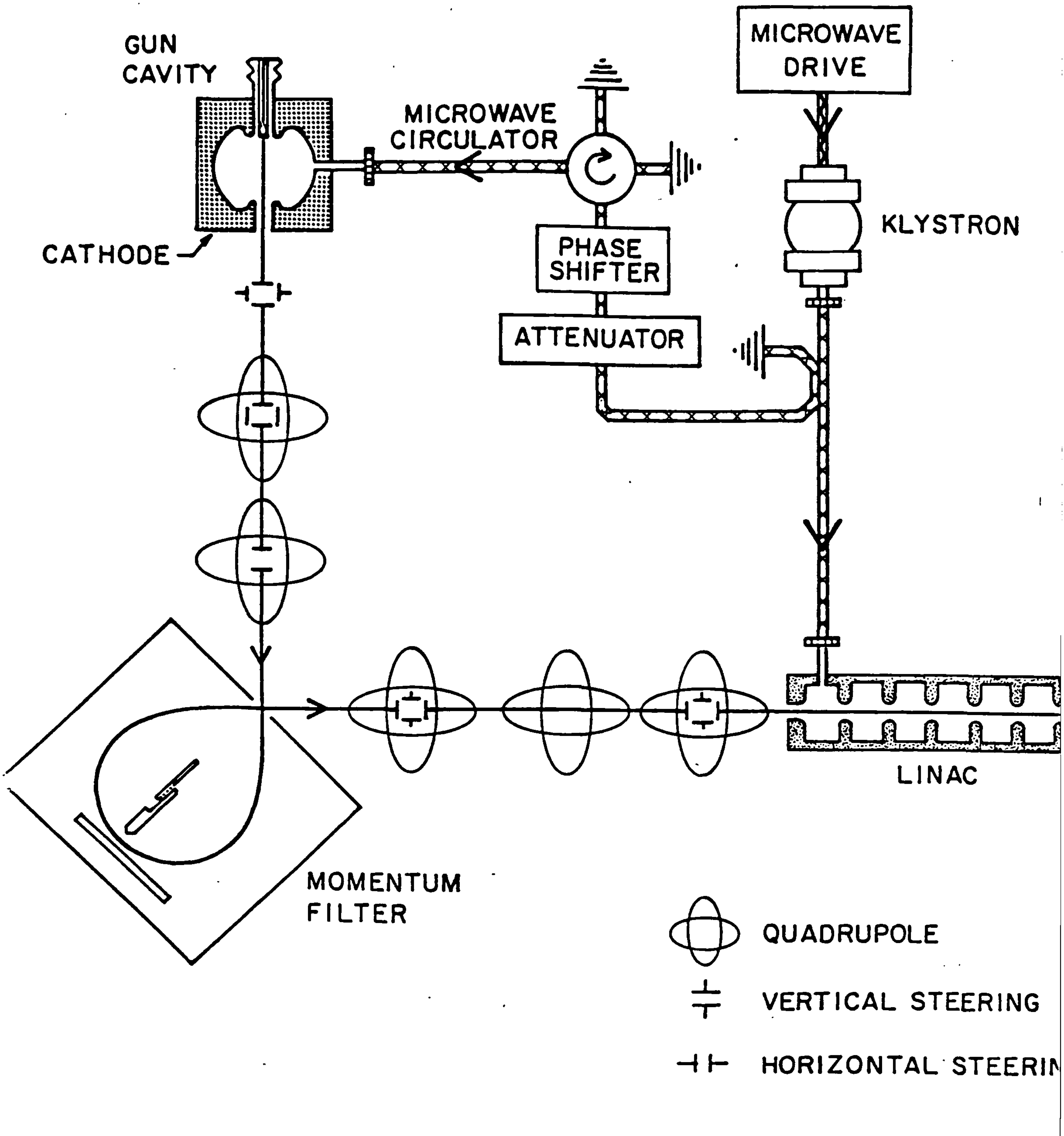
*** LABOR ***	# of Units	Units hr	Total M Hrs	Craft Code	Total Labor
	1.00	40	40	ME	1785
	1.00	40	40	TV	1501
Total Labor					3286
Total 1.1.4.6					45521

1.1.4 LINEAR ACCELERATOR SYSTEMS

1.1.4.7 Beam Diagnostics

*** MATERIALS ***	Unit	# of Units	Unit Cost	Cost Base	Total $
BPM Electronics	set	6	1250	SP86	7500
Current Monitor	each	1	1000	EU	1000
Beam Steering/PS	each	6	1500	EU	9000
Analyzing Station:					
Bending Magnet(refurb.)	each	1	250	EU	250
Quadrupoles (refurb.)	each	2	250	EU	500
Power Supplies	each	3	1600	CP	4800
Supports	each	3	500	EU	1500
Vacuum Chambers	set	1	3000	EU	3000
Instrumentation	each	1	5000	EU	5000
Electronics	each	1	5000	EU	5000
Contract Labor	hr	400	JL	EU	7180
Total Materials					44730

*** LABOR ***	# of Units	Units hr	Total M Hrs	Craft Code	Total Labor
	1.00	120	120	EE	5296
	1.00	240	240	TM	9005
Total Labor					14302
Total 1.1.4.7					59032


GUN
CAVITY
CATHODE
MICROWAVE
CIRCULATOR
PHASE
SHIFTER
ATTENUATOR
MICROWAVE
DRIVE
KLYSTRON
LINAC
MOMENTUM
FILTER
QUADRUPOLE
VERTICAL STEERING
HORIZONTAL STEERIN

4-9-86 M. MARK

Master Oscillator	10	TWT [illegible] power supply
RF drive	50	
Timing system / controls	20	~ 40 MW [illegible]
RF diagnostics	2	

Accel. sections

1) Scientific Instrument [illegible]
MTG [illegible] Gelnhausen
l = 3m 75k$ Feb 1985

2) MITSUBISHI
l = 3m 36k$

3) CGR MeV
l = 3m 1,662,000 FF ≈ 146k$
1 - 2

High pwr Modulators

			Material	Tech (each mod.)	Prof (3 mod.)	
HV	1	Variac variac	5K	.2 W	1W	
HV	1	PWR xformer	3K	.2 W	1W	
P	1	~~Set~~ set of Diodes	1K	.3 W	1W	
P	2	relay	.5K	.2 W		
P	3	fuses	.2K	.2 W		
P	3	Toroids	.3K ~~.15~~	.2 W	1W	
P	1	Filter choke	1.5K	.5 W	1W	
P	1	Filter ~~cap & chan~~ capacitors	1K	.2 W	1W	
P	1	charging choke	1.5K	.5 W	2W	
P	1	fuse	.2K	.2 W	.5W	
P	1	set of charging Diodes	.2K	.5 W	1W	
P	1	set of capacitor P.F.N	5K	1 W	2W	
P	1	set of coils P.F.N	.5K	1 W	2W	
P	1	E.O.L Network	2K	1 W	2W	
K	1	Tank + fans + RFI gaskets (refurbish)	1K ~~5K~~	2 W	3W	SLA
P	1	Thyratron English Electric (ITT 8K)? problems	18 ~~12~~K	.2 W	2W	
P	1	PWR sup for thyratron (3 xformer + electronics + grading)	2K	2 W	5W	
HV	1	oil and/or SF6	.5K	.2 W	1W	
PPFN	1	VOLTAGE divider	.2K	.2 W	1W	
C	1	PFN charging signal	.2K	.2 W	1W	
C	1	micro computer	1K	1 W	8W	
C	1	electronic box	1K	1 W	4W	
C	1	Bias pwr sup	.5K	1 W	3W	
C	1	Filament PWR sup	1K	1 W	3W	
HV	1	cabinet for PWR supp + Mod	10K	1 W	4W	
C	1	Electronics Rack 62" 10-RA 611314	.5K	.1 W	4W	$2000
			55.8K	17 W	55W	

C 3 trigger box 3K 1MW Prof

P TUNNING PFN .5 W

17.5W

from SLAC

tank } for klystron
cable }
add labor for: assembly 1MW

~~add 25% on manpower for PFN~~

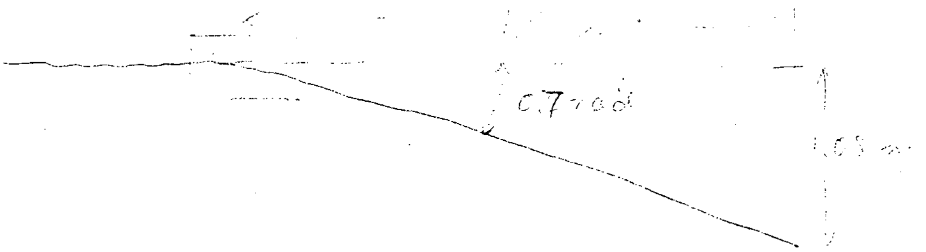
Analyzing Station: $E = 100$ MeV

use our old model:

$\rho = 36$ mm $I = $ [illegible] amp
$B = 13.1$ kG $V = 32$ V
$l = 0.4$ m

$$\varphi = 0.03 \frac{13.1 \cdot 0.4}{0.1} = 1.57 \text{ rad}$$

need $y \approx 1$ m at 1.5 m from bend $\Rightarrow \varphi' = 0.7$ rad



new bend is:

$\varphi = 0.7$ rad
$l = 0.4$ m
$B = 5.83$ kG

$I = $ [illegible].6 amp
$V = 14.1$ V

Circulator: FCI ~~[illegible]~~ COMPONENTS INC.
FERRITE

(617) 250-1673

Contact: ELDO ELICONE

10 KIDDER ROAD
CHELMSFORD, MA, 01824

$1500.— 3 month.

wave guide: S-Band

MTI Microwave Techniques Inc.

(207) 655-3881

~~[illegible]~~ Road 302

RAYMOND, ME, 04071

SPEAR Injection Parameter

3 GeV SPEAR Injection System

Electron Beam Parameter

Micro Wave Gun/Positron Source

Beam Energy at End of Linac (MeV)		100.000
Cathode Peak Current (amp)		10.000
Total Bunch Length (mm)		2.000
Particles/S-Band Bunch (1.0E08)		4.167
Energy Spread due to Bunch Length		0.002
Particles per 3 S-band Bunches (1.0E08)		12.500
Number of Booster Bunches		1.000
Number of Particles per Cycle (in 1.0E08)		12.500
Total Energy Spread at full Linac Energy		0.010
Normalized Beam Emittance (FWHM/2)(eps*gamma)		
	Horizontal (E-06 m)	20.000
	Vertical (E-06 m)	10.000
Beam Emittance	Horizontal (E-06 m)	0.102
	Vertical (E-06 m)	0.051

Storage Ring Injection Time	single Bunch	multi Bunch
Storage Ring Beam Current (ma)	30.00	100.00
Circumference (m)	234.00	234.00
Total Number of Particles (1.0E08)	1462.50	4875.00
Injection Efficiency (%)	25.00	25.00
Number of Bunches in Booster	1.00	8.00
Number of Booster Cycles needed	468.00	390.00
Booster Cycles per Second	2.00	2.00
Storage Ring Filling Time (min)	3.90	1.62
Storage Ring Filling Rate (ma/min)	7.69	~~30.77~~ 61.54

Beam Size at Injection into Booster

Max.Beta Function	Horizontal	(m)	6.600
	Vertical	(m)	8.150
Max.Eta Function		(m)	1.700
Total max. Beam Width (mm)			1.643
Total max. Beam Height (mm)			1.291

1.1.5 MAGNET SYSTEM

1.1.5.0 E D & I

*** LABOR ***	# of Units	Units MM	Total MM	Craft Code	Total Labor
Electr. Engineering	1	9	9	EE	68719
Mech. Engineering	1	24	24	ME	185275
Mechanical Designer	1	12	12	MD	65847
Electrical Designer	1	6	6	ED	32924
Coordinator	1	9	9	CS	47284
Total Labor					400049
Total 1.1.5.0					400049

1.1.5 MAGNET SYSTEM

1.1.5.1 Magnets

1.1.5.1.1 Bending Magnet

*** MATERIALS ***	Unit	# of Units	Unit Cost	Cost Base	Total $
Sheet Iron	1000 lb	240	400	VQ	96000
Stamping Die	each	1	20000	VQ	20000
Stamping	1000	75	500	VQ	37500
End Plates	1000 lb	10	1000	EU	10000
Stacking Fixture	each	1	20000	EU	20000
Stacking/Welding	block	280	200	EU	56000
Copper	1000 lb	20	2500	VQ	50000
Copper Die	each	1	6000	VQ	6000
Coils/Magnet Assembly	each	70	1600	SP86	112000
Water Hoses	each	256	5	A86	1280
Bucking Magnet	each	1	10000		10000
Contract Labor	hr	1440	JL	EU	25850
Total Materials					444630

*** LABOR ***	# of Units	Units hr	Total MM	Craft Code	Total Labor
End Plates	64	4	1.5	MM	6695
Stacking Fixture	1	80	0.5	TM	3002
Engineering	32	8	1.48	ME	11424
Assembly	32	8	1.48	TM	9606
Total Labor					30726

Total 1.1.5.1.1	475356

1.1.5 MAGNET SYSTEM

1.1.5.1 Magnets

1.1.5.1.2 Quadrupoles

*** MATERIALS ***	Unit	# of Units	Unit Cost	Cost Base	Total $
Sheet Iron	1000 lb	13	400	VQ	5200
Stamping Die	each	1	10000	VQ	10000
Stamping	1000	52	300	VQ	15600
Stacking Fixture	each	1	3835	EU	3835
Stacking/Welding	set	160	50	EU	8000
Coils/Magnet Assembly	each	160	650	SP86	104000
Water Hoses	each	288	5	A86	1440
Contract Labor	hr	320	JL	EU	5744
Total Materials					153819

*** LABOR ***	# of Units	Units hr	Total MM	Craft Code	Total Labor
Stacking Fixture	1	80	0.46	TM	3002
End Plates	320	1	1.85	MM	8369
Engineering	32	8	1.48	ME	11424
Assembly	32	8	1.48	TM	9606
Total Labor					32400

Total 1.1.5.1.2	186220

1.1.5 MAGNET SYSTEM

1.1.5.1 Magnets

1.1.5.1.3 Sextupoles

*** MATERIALS ***	Unit	# of Units	Unit Cost	Cost Base	Total $
Sextupole Cores	each	22	600	SP86	13200
Sextupole Coils	each	132	243	A86	32076
Steering Magnets	each	12	500	EU	6000
Magnet Assembly	each	22	300	EU	5760
Brackets for Sextupoles	each	22	102	A86	2244
Water Hoses	each	264	5	A86	1320
Contract Labor	hr	176	JL	EU	3159
Total Materials					63759

*** LABOR ***	# of Units	Units hr	Total MM	Craft Code	Total Labor
Sextupole Assembly	22	8	1.02	TM	6604
Steering Magnets	12	2	0.14	TM	901
Total Labor					7504
Total 1.1.5.1.3					71264

1.1.5 MAGNET SYSTEM

1.1.5.2 Magnet Support

*** MATERIALS ***	Unit	# of Units	Unit Cost	Cost Base	Total $
I-Beam	ft	329	360	A86	118440
Fine Adjustments	set	90	670	A86	60300
Assembly	set	90	50	EU	4500
Clamps	set	270	9	A86	2354
Footing	each	96	75	SP86	7200
Misc. Materials	lot	1	1500	EU	1500
Concract Labor	hr	576	JL	EU	10340
Total Materials					204634

*** LABOR ***	# of Units	Units hr	Total MM	Craft Code	Total Labor
Assembly	90	4	2	TM	13508
Total Labor					13508

Total 1.1.5.2	218142

1.1.5 MAGNET SYSTEM

1.1.5.3 Alignment

*** MATERIALS ***	Unit	# of Units	Unit Cost	Cost Base	Total $
Materials	set	90	100	EU	9000
Contract Labor	hr	720	JL	EU	12925
Total Materials					21925

*** LABOR ***	# of Units	Units hr	Total MM	Craft Code	Total Labor
Alignment Engineer	36	1	0.21	AE	1361
Alignment Technician	90	4	2.08	TA	11078
Raft Alignment in Tunnel	36	8	1.66	DB	15549
Total Labor					27988

Total 1.1.5.3	49913

1.1.5 MAGNET SYSTEM

1.1.5.4 Magnet Measurement

*** MATERIALS ***	Unit	# of Units	Unit Cost	Cost Base	Total $
Hall Probe	each	1	3500	CP	3500
Harmonic Coil	each	1	1100	SP86	1100
Magnet Lifter	each	1	950	CP	950
Cooling Fixtures	set	1	500	EU	500
Micro Computer	each	1	6500	CP	6500
Misc. Materials	lot	1	1500	EU	1500
Bend Magnet Track	each	3	1000	SP86	3000
Magn. Meas. Stand	all	1	17000	SP86	17000
Computer Interface	set	1	16000	SP86	16000
Total Materials					50050

*** LABOR ***	# of Units	Units hr	Total MM	Craft Code	Total Labor
Magnetic Measurement	90	1	1	EE	3972
	90	12	6	TM	40524
Programming	1	346	2	ST	3195
Total Labor					47691

Total 1.1.5.4	97741

1.1.5 MAGNET SYSTEM

1.1.5.5 Magnet Power Supplies

*** MATERIALS ***	Unit	# of Units	Unit Cost	Cost Base	Total $
Bending Magnets	kW	300	310	SLAC	93000
Quadrupole Supplies	kW	120	480	SLAC	57600
Sextupole Supplies	kW	60	480	SLAC	28800
Small Supplies	each	30	1600	A86	48000
Bulk Supply	each	3	2000	SP86	6000
Transducers	each	5	990	SP86	4950
Interlock	each	5	500	SLAC	2500
Interface Chassis	each	5	2500	SP86	12500
Misc. Materials	lot	1	2000	EU	2000
Contract Labor	MM	10	JL	EU	31056
Total Materials					286406

*** LABOR ***	# of Units	Units MM	Total MM	Craft Code	Total Labor
Installation	2.00	6	12	TE	50951
Total Labor					50951

Total 1.1.5.5	337356

1.1.5 MAGNET SYSTEM

1.1.5.6 Magnet Installation

*** MATERIALS ***	Unit	# of Units	Unit Cost	Cost Base	Total $
Installation Material	set	32	150	EU	4800
main Magnet Cables (5)	100ft	27.5	200	SLAC	5500
small Magnet Cables	100ft	110	25	SP86	2750
Total Materials					13050

*** LABOR ***	# of Units	Units hr	Total MM	Craft Code	Total Labor
Magnet Raft Installation	32	24	4.44	DB	41463
Install Magnets on Rafts	90	4	2.08	TM	13508
main Magnet Cables/Inst.	2750	0.06	0.99	DB	9279
small Magnet Cables/Inst.	11000	0.01	0.64	DB	5939
Total Labor					70189

Total 1.1.5.6	83239

8-4-87

SPEAR 3.0 GeV Injector

Bending Magnet Specification

General Parameter:

Magnet Name in Lattice	B	B1	B2	Block
Magnet Designation	34HB2000	34HB1200	34HB1200	34HB400
Magnet Type	laminated	laminated	laminated	laminated
Magnetic Arc Length (mm)	2000.00	1200.00	1200.00	400.00
Bending Radius (mm)	7639.44	7639.44	11459.16	7639.44
Bending Angle (radian)	0.262	0.157	0.105	0.052
Bending Angle (degrees)	15.00	9.00	6.00	3.00
Sagitta (mm)	65.36	23.55	15.70	2.62
Number of Magnets	16.00	8.00	8.00	1.00
Beam Energy (GeV)	3.00	3.00	3.00	3.00
Gap Height (mm)	36.00	36.00	36.00	36.00
Field (kGauss)	13.10	13.10	8.73	13.10
Maximum Field (kGauss)	15.70	15.70	10.47	15.70
Total Current/Coil (amp)	18762.98	18762.98	12508.65	18762.98
Length of Iron Block (mm)	1964.00	1164.00	1164.00	364.00
Cross Section/Coil (mm^2)	7310.00	7310.00	4845.00	7310.00
Aluminum Fill Factor	0.75	0.75	0.75	0.75
Power at nom. Energy (kW)	17.83	11.46	7.44	5.09
Number of Turns/Coil	9	9	6	9
Current (amp)	2087	2087	2099	2087
Elect.Resist./Magnet (mOhm)	4.09	2.63	1.69	1.17
DC-Voltage/Magnet (Volt)	8.54	5.49	3.54	2.44
Induction/Magnet (mHenry)	2.16	1.28	0.56	0.40
Cycling Rate (Hz)	2.00	2.00	2.00	2.00
Impedance (mOhm)	27.39	16.27	7.25	5.15

System Parameters:

Beam Energy (GeV)	3.00	3.50	3.60	3.75
Total Deflection Angle	360.00	360.00	360.00	360.00
Total Raw Iron Weight (lb)	188280.58	116050.18	81018.43	21909.89
Total Iron Weight (lb)	145988.57	89982.73	62819.89	16988.44
Total Aluminum Weight (kg)	5214.54	5214.54	5214.54	5214.54
Total Electr. Power (kW)	436.45	594.06	628.49	681.96
Total DC-Voltage (Volt)	208.99	243.82	250.79	261.24
Total # of Lams	39589.29	11731.65	11731.65	458.58

SPEAR 3.0 GeV Injector

Bending Magnet Specification

Mechanical Dimensions:

Magnet Name in Lattice	B	B1	B2	Block
Width of Magnet (mm)	500.00	500.00	500.00	500.00
Height of Magnet (mm)	450.00	450.00	450.00	450.00
Width of return Yoke (mm)	80.00	80.00	80.00	80.00
Pole Width (mm)	100.00	100.00	100.00	100.00
Width of Pole Root (mm)	120.00	120.00	120.00	120.00
Length of Pole (mm)	84.00	84.00	84.00	84.00
Pole Gap Height (mm)	35.00	35.00	35.00	35.00
Iron Cross Section (mm^2)	174460.00	174460.00	174460.00	174460.00
Raw Iron Weight (lb)	7388.57	4378.97	4378.97	1369.37
Iron Weight (lb)	5728.93	3395.35	3395.35	1061.78
Length of Iron Block (mm)	1964.00	1164.00	1164.00	364.00
Lamination Thickness (mm)	1.588	1.588	1.588	1.588
# of laminations	2474.33	1466.46	1466.46	458.58
Coil Cross Section:				
Height (mm)	85.00	85.00	85.00	85.00
Width (mm)	86.00	86.00	57.00	86.00
Coils Shape	flat	flat	flat	flat
Length (mm)	4478.18	2878.18	2787.07	1278.18
Aluminum Fill Factor	0.75	0.75	0.75	0.75
Al Cross Section (mm^2)	5482.50	5482.50	3633.75	5482.50
Al Weight per Coil (lb)	145.84	93.73	60.16	41.63
Electr. Resistance(mycro Ohm)	25.32	16.27	23.78	7.23
Elect. Power/Coil (kWatt)	8.91	5.73	3.72	2.54
Conductor Width (mm)	7.50	7.50	7.50	7.50
Height (mm)	88.00	88.00	88.00	88.00
Cooling Hole Diam.(mm)	8.00	8.00	8.00	8.00
Number of Turns	9.0	9.0	6.0	9.0

```
3 GeV SPEAR Injector Synchrotron

Quadrupole Specification            10-19-1986    10-19-1986
============================================================


Magnet Name in Lattice                      QF            QD
Magnet Designation                      30Q287        30Q287
Magnet Type                           straight      straight
Straight Magnetic Length (mm)          287.200       287.200



Energy (GeV)                             3.000         3.000
Bore Radius (mm)                        30.000        30.000
Field Gradient (G/cm)                 1978.700      1449.300
Maximum Field Gradient (G/cm)         2400.000      2400.000
Total Current/Coil (amp)              7085.697      5189.923
Length of Iron Block (mm)              257.200       257.200
Weight of Iron (lb)                    744.207       744.207
Coil Cross Section/Coil (mm^2)        1600.000      1600.000
Aluminum Fill Factor                     0.750         0.750
AL in all 4 Coils (lb)                  39.350        39.350
El. Power at nom. Energy (kW)            7.160         3.841

Number of Turns/Coil                     8.000         8.000
Current (amp)                          885.712       648.740
El.Resistance/Magnet (mu_Ohm)            9.127         9.127
Voltage/Magnet (Volt)                   32.336        23.685
Number of Magnets                       18.000        18.000
===========================================================

System Parameters:

Beam Energy (GeV)                        3.000         3.600
Total Iron Weight (lb)               13395.731     13395.731
Total Al Weight (lb)                   708.303       708.303
Total Electr. Power (kw)               128.884       185.592
Total Voltage (Volt)                   582.056       698.467
Total # of Lams                      13025.764     13025.764
```

```
          Width of Magnet (mm)       416.00       416.00
         Height of Magnet (mm)       416.00       416.00
     Iron Cross Section (mm^2)    173056.00    173056.00
         Raw Iron Weight (lb)        744.21       744.21
              Iron Length (mm)       287.20       287.20
    Lamination Thickness (mm)         1.588        1.588
        Number of Laminations        723.65       723.65



           Coil Cross Section:
                   Height (mm)        20.00        20.00
                    Width (mm)        80.00        80.00
                   Coils Shape         flat         flat
                   Length (mm)      1380.13      1380.13
        Aluminum Fill Factor           0.75         0.75
      AL Cross Section (mm^2)       1200.00      1200.00

      Al Weight per Coil (lb)          9.84         9.84
 Resistance/Coil (mycro Ohm)          35.65        35.65
    Elect. Power/Coil (kWatt)          1.79         0.96
```

J.M. Voss

Magnet Cost | 3 GeV SSRL Booster | Bend Magnets 7/13/87

Mant-2

No. Lamminations: Magnet 8" high x 19" Wide x 14.33 long (½ core)

Take lammination of 9" x 20" x 1/16" ~ 250 lamminations per ½ core x 256 ½ cores ~ 65000 lamminations

Say 75000 lamminations with 15% spares.

Total Steel weight

Take strip stock 20" wide – yields 56250 ft. of coil. Lammination weight is 20 x 9 x .0625 x .283#/in³ = 3.183# per lammination stock. 75000 lamminations at 3.2 lb/lammination ~ 240,000 lbs of Steel

Steel Cost: Verbal budgetary quotes from Larry Wonacol SLAC purchasing based on contact with Ryerson and Worthington will yield a cost of 40¢/lb including shipping and packing. 240,000 lbs @ .40¢/lb = $96,000

Die Cost: Verbal estimates from Kurt Schultz - Schultz Mfg ~ $16,000 Leo Hoenighausen $12,000. Take high of $16000 + 4,000 for Modifications. $20,000

Cost per lammination: w/o tight tolerance and straightening needed for SLC cost per hit for 75,000 lamminations will be .30¢/hit. Take 50¢/hit yields a cost of $37,500 stamping cost

50#/end plate

End Plates – 10,000 lbs @ 1.00/lb finished ~ $10,000

Stacking & welding – Based on recent history at SLAC Shops

Stacking fixture – $20,000 (past history)

Stacking & Welding assembly – $200 mat'l/Block x 280 = $56,000

Page 1 of 4

J.M. Voss

Magnet Cost | 3 Gen SSRL/Booster | Bend Magnets | 7/13/87

Coils – ~~One~~ — $6000 – present cost Arizona Alum
aluminum – 12000 lbs @ 2.50/lb = 30,000
Aluminum coil preinsulation + 20000
50,000

23hrs/coil

Coil assembly / pair to 40hrs @ $40.00 = 1600 ea
for 70 coils ~ 70×1600 = 112,000

Water hoses – per SPRL made @ SLAC 4.75 each
256×5 = $1280.00

Bucking Magnet — $10,000

Contract Labor –

Coils	740	(32@24hrs)	940
Coils	700	(70@10 hrs each)	560
	1440 @ 17.95 = $25850		

Labor
to be added?

Page 2 of 4

Magnet Cost | 3Gev SSRL/Booster | Quad Magnets Sextupole | JMV083 7/13/87

Material per SPRL Design

			k$
Steel	13000 lbs @ .40$/lb	~	5200
Stamping Die		~	10,000 (per Schlitz)
Stamping	52000 lams @ .3	~	15,600
Stacking Fixture/Modify existing 110hr	@34.95	~	3,835
Stacking/Welding	160 quadrants @ 50	~	8000
Coils/Per SPRL (Elma Eng)	160 @ 650	~	104 000
Water hoses	288 @ 5	~	1440
Contract labor	320hrs @ 17.95	~	5744
			153,820

Labor – to be added

Sextupole (per SPRL Design) / RT Enterprises & Elma

Material

Sextupoles cores	22 @ 600	(RT Enterprises)	13,200
Sextupole Coils	132 @ 243	(Elma Eng)	32076
Steering Magnets	12 @ 500		6000
Magnet assembly	22 @ 300		5760
Mounting brackets	22 @ 102		2244
Hoses Water	264 @ 5		1320
Contract Labor	176 @ 17.95		3159
			$63,760

Labor) – to be added

Supports

Girder	329' @ 360/FT	(SPRL)	118440
Fine adjustment	90 @ 670	(SPRL)	60,300
Assembly	90 @ 50	(est)	4500
Clamp	270 @ 5	(SPRL)	2354
Footings	32x3=96 @ 75.00	(SPRL)	7200
Material			1500
Contract labor	576 @ 17.95		10340
			204,630

assembly – to be added

Alignt / Alignment / 36in 8SRL / Booster Alignment JT.NO3 7/13/87

Material	90 magnets @ 100	—	9000
Contract labor	90 × 8 × 17.95	—	12925

Labor – to be added

Magnet installation

~~Material~~	32 girders @ 150	4800
Main buss pwr.	2750 FT @ 2.00/FT	5500
Other cables	11000 @ .25/FT	2750
		13,050

Installation

Girder Installation	32 @ 8 × 3 × @54.00	~ 41463
Magnets on Girders	90 @ 8 × 17.95	~ 13500
Main Cable install	2750 @ .06/FT @ 54.00	~ 9275
Small Cables	11000 @ .01 @ 54.00	~ 5939
		83,239

17[illegible]/MONTH
@ 9330.51
9280 @ 54.00

Comparison of Magnet Costs.

	SPRL	SPRL scaled to Inj.	Injector Est
BEND:			
length (m)	0.28	~~0.28~~ 2.0 / 1.2	2.0 / 1.2
iron block*	$1789	12800 / 7667	10760 / 6460
Coils ~~form~~	dog eared	flat	flat
	~~$3172/pair~~	~~5890 / 4380~~	~~5900~~
	$3172/pair		$3200/pair

Total Cost

	SPRL scaled to Inj.	Injector Est
IRON	327 K	275
COILS	102 k	102
~~Copper~~	~~75k~~	
	429 k	377

SPRL iron blocks are
precision machined
all around.

Water Hoses for Magnets.

SPRL Magnets (W. Wadensweiler)

400 hoses each 3 ft with fittings
(made at SLAC)

total cost : $1890

or $ 4.725 /hose

QUOTATION LIST

FILE NAME PRICE	WW-14	WW-15		WW-16		WW-17	WW-18		WW-19			
	BM STL. 53	QD20 32 (24)	QD30 24 (22)	QF20 22 (20)	QF30 7 (5)	SEXT. 45	QD PLT. 20	QF PLT. 20	CLAMP TOP 130	PLT. BM 40	BRKT. SXT. 45	TRML. SXT. 180
HRV ENGINEERING REDWOOD CITY	NO QUOTE	$1692.50 $1523	$1480 ADDIT. (PAY ADVANCE)	$2293.00 $2100	$2000 ADDIT. (PAY ADVANCE)	$1789.00	NO QUOTE		$12.00	$135.00	$115.00	$45.00
		LOT: $84858 PAY ADDV		LOT: $80500 PAY ADDV		$80505				LOT: $20235.00		
BENNET-HOPKINS REDWOOD CITY	NO QUOTE	$1985.25		$2425.20		$775.00	$851.40	$897.60	$17.30	$84.10	$106.75	$29.80
		LOT: $111174.00		LOT: $70330.80		$34875	LOT: $34980.00			LOT: $18516.75		
ALLIED ENGINEERING REDWOOD CITY	$3667.00	$3467.00		$4087.00		$1100.00			$19.00	$122.00	$299.00	$62.00
	$194351	LOT: $194152		LOT: $118523		$49500	4-5 MOS.			LOT: $31965.00		
LB MACHINING BELMONT	NO QUOTE						$838.00		$11.85	$108.00	$110.00	$25.00
							LOT: $33520.00			LOT: $15310.50		
ASSOCIATED MAC SANTA CLARA	NO QUOTE						$1231.00	$1220.00	$15.00	$79.00	$217.00	$50.31
							6-8 WKS.			LOT: $31435.80		
RT ENTERPRISES BELMONT	$1789.60	$1662.03	$1681.10	$2001.60	$2304.20	$599.44	$656.50	$718.75	$8.72	$93.27	$101.20	$30.88
	$94848.80	LOT: $93531.36		LOT: $60164.60		$26974.80	LOT: $27505	4-6 WKS		LOT: $14976.80		
ED. ENTERPRISES NEWARK	NO QUOTE											
CITY TOOL & DIE SANTA CLARA	NO QUOTE											
TRID PRECISION CAMPBELL	NO QUOTE											
HOLZ PRECISION SAN JOSE	$3800.00	$5600.00		$7500.00		$4400.00	$1550.00		NO QUOTE			
	$201400	LOT: $313600		LOT: $217500		$198000	LOT: $62000					
WESS-DEL INC. SANTA CLARA	$2365.00	NO QUOTE					$828.00 / $33210.00		NO QUOTE			
	$124868						90 DAYS					
HOLT TOOL & DIE REDWOOD CITY	NO QUOTE	NO QUOTE					$838.00 / $33520		$11.85	$108.00	$110.00	$25.00
							LOT: $33520.00			LOT: $15310.50		
PROTOTYPE	$2245	3000.00		$5000.00		$785.00	$990.00					
TOTAL	$94848.80	$84858		$60500		$26974.80	$27505.00		$14976.80			

SPRL COIL BIDS

	WW-20 BENDING MAG.			WW-21 QD MAGNET			WW22 QF MAGNET			WW-23 SEXTUPOLE MG.		
	1ST UNIT	48 UTS ADD EA	53 TOTAL	1st UNIT	46 units ADD EA	56 TOTAL	1st UNIT	25 UNITS ADD EA	29 TOTAL	1st UNITS	40 units Add EA	45 TOTAL
ALPHA	5000	3172/3172	$168116	3326	2846/2846	$159376	$5640	3375/3375	$39175	$4153	2417/2417	$108765
ELMA	11898	4817/4648	$239456	4190	2046/1940	$113576	$2600	2033/1940	$72920	$1480	1480/1290	$65650
EVERSON	16,500	11500/11500	$609500	10600	3800/3850	$215600	$9800	3900/3900	$111,100	$10,500	3500/3500	$157,500
ULRICH	12,385	4725/4725	$250425	[illegible]	2110/2110	$118160	10350	2277	$66033	1870	[illegible]	$97765-
BUYER		NO QUOTE			NO QUOTE			NO QUOTE			NO QUOTE	

Steel: ≈10 weeks
finish: 5 month 3-5 month
Coil: 6 month all starting in 3 month

6-7 month

TOTAL $413,375 MIN

1.1.6 VACUUM SYSTEM

1.1.6.0 E D & I

*** LABOR ***	# of Units	Units MM	Total MM	Craft Code	Total Labor
Electr. Engineering	1	2	2	EE	15271
Mech. Engineering	1	9	9	ME	69478
Mechanical Designer	1	12	12	MD	65847
Electrical Designer	1	2	2	ED	10975
Total Labor					161571
Total 1.1.6.0					161571

1.1.6 VACUUM SYSTEM

1.1.6.1 Vacuum Chambers

1.1.6.1.1 Vacuum Chamber Components

*** MATERIALS ***	Unit	# of Units	Unit Cost	Cost Base	Total $
Conflat Flanges 4.5"	each	5	61	CP	305
Feed thru for BPM	set	4	65	CP	260
SST Tubing	each	2	4	EU	8
Junction Block	each	1	24	CP	24
BPM Parts	set	1	20	EU	20
Bellows	each	1	200	EU	200
Oval Flexture	each	6	5	EU	30
Tooling/Oval Flexture	each	0.031	5000	EU	156
Thin Tubing	ft	9	24	EU	204
Stiffening Ribs	each	270	0.50	EU	135
Tooling for Ribs	each	0.031	5000	EU	156
Total Materials/Chamber	32 units				47952

*** LABOR ***	# of Units	Units hr	Total MM	Craft Code	Total Labor
Machining	1	34	0.20	MM	900
Total Labor	32 units				28811
Total 1.1.6.1.1	32 units				76763.36

1.1.6 VACUUM SYSTEM

1.1.6.1 Vacuum Chambers

1.1.6.1.2 Vacuum Chamber Assembly

*** MATERIALS ***	Unit	# of Units	Unit Cost	Cost Base	Total $
Braze Flanges	each	14	10	EE	140
Tooling for Brazing	set	0.031	5000	EU	156
Braze Alloy	lot	1	100	EE	100
Brazing	each	1	1300	EE	1300
Total Materials/Chamber	32 units				54280

*** LABOR ***	# of Units	Units hr	Total MM	Craft Code	Total Labor
Welding	1	6.25	0.04	WV	235
Total Labor/Chamber	32 units				7504
Total 1.1.6.1.2	32 units				61784

1.1.6 VACUUM SYSTEM

1.1.6.1 Vacuum Chambers

1.1.6.1.3 Straight Section

*** MATERIALS ***	Unit	# of Units	Unit Cost	Cost Base	Total $
Tubing, thin	ft	7	15	EU	105
Bolt Set	set	1	35	CP	35
Rib Stamping	each	100	0.50	EU	50
Flanges 4.5"	each	4	61	CP	244
Total Materials	4 units				1736

*** LABOR ***	# of Units	Units hr	Total MM	Craft Code	Total Labor
Welding	1	12	0.07	WV	450
Total Labor	4 units				1801
Total 1.1.6.1.3	4 units				3537.06

1.1.6 VACUUM SYSTEM

1.1.6.1 Vacuum Chambers

1.1.6.1.4 Welding Station

*** MATERIALS ***	Unit	# of Units	Unit Cost	Cost Base	Total $
300amp Miller Tigwelder	each	1	2789	CP	2789
Foot Control	each	1	121	CP	121
misc. welding materials	lot	1	710	EE	710
Welder Gas Helium	Cyl	1	20	CP	20
Welder Gas Argon	Cyl	6	20	CP	120
Regulators/Flow Meter	set	2	250	CP	500
Hoses/Valves/Fan/Duct	each	1	350	CP	350
Welder's Table	each	1	450	EU	450
Total Materials					5060

*** LABOR ***	# of Units	Units MM	Total MM	Craft Code	Total Labor
Total Labor					0
Total 1.1.6.1.4					5060

1.1.6 VACUUM SYSTEM

1.1.6.~~3~~2 Pumping System

1.1.6.2.1 Roughing System

*** MATERIALS ***	Unit	# of Units	Unit Cost	Cost Base	Total $
Cross	each	4	113	CP	452
Double Vacsorbs	each	4	897	CP	3588
LN2 Dewar	each	2	920	CP	1840
Heating Band	each	4	245	CP	980
Convection Gauge	each	4	481	CP	1924
Right Angle Valves	each	8	454	CP	3632
Mobile Mech. Pump	each	1	2350	CP	2350
misc. Parts	lot	1	1000	EU	1000
Total Materials					15766

*** LABOR ***	# of Units	Units MM	Total MM	Craft Code	Total Labor
Total Labor					0
Total 1.1.6.2.1					15766

1.1.6 VACUUM SYSTEM

1.1.6.2 Pumping System

1.1.6.2.2 Ion Pumping System

*** MATERIALS ***	Unit	# of Units	Unit Cost	Cost Base	Total $
Ion Pump 8 lt/sec	each	32	735	CP	23520
Reducing Flange	each	32	80	CP	2560
Medium Pump Supplies	each	8	1600	CP	12800
Gate Valves	each	2	10900	CP	21800
Ion Pump for RF Cavity	each	1	9280	CP	9280
Supply for RF Pump	each	1	1845	CP	1845
Total Materials					71805

*** LABOR ***	# of Units	Units MM	Total MM	Craft Code	Total Labor
Total Labor					0
Total 1.1.6.2.2					71805

1.1.6 VACUUM SYSTEM

1.1.6.3 Pressure Monitoring

*** MATERIALS ***	Unit	# of Units	Unit Cost	Cost Base	Total $
Ion Gauge	each	8	325	CP	2600
Gauge Controller	each	8	875	CP	7000
Tee's	each	8	90	CP	720
Model 531 TC Gauge	each	8	48	CP	384
Total Materials					10704

*** LABOR ***	# of Units	Units MM	Total MM	Craft Code	Total Labor
Total Labor					0

Total 1.1.6.3	10704

1.1.6 VACUUM SYSTEM

1.1.6.4 Cleaning/Installation

*** MATERIALS ***	Unit	# of Units	Unit Cost	Cost Base	Total $
Solv.(Alco.,Acet.,Freon)	lot	1	2134	SP86	2134
Gloves,Foil,Towels	lot	1	3750	SP86	3750
Alum.Foils	roll	18	7.43	SP86	134
Plastic Foil/Bags	lot	1	750	SP86	750
Hardware(nuts,bolts etc)	each	1000	0.57	SP86	570
misc. Supplies	lot	1	4510	SP86	4510
Plastic Bags	lot	1	500	SP86	500
Clean Room Equipment	set	1	1215	SP86	1215
Gaskets	each	300	2	SP86	600
LN2 Dewar	each	2	920	CP	1840
Contract Labor	MM	18	JL	EU	55900
Total Materials					71903

*** LABOR ***	# of Units	Units MM	Total MM	Craft Code	Total Labor
Vacuum Engineer	1.00	6	6	ME	46319
Installation Labor	1.00	9	9	TV	58422
Total Labor					104741
Total 1.1.6.4					176643

1.1.6 VACUUM SYSTEM

1.1.6.5 Beam Monitoring

*** MATERIALS ***	Unit	# of Units	Unit Cost	Cost Base	Total $
Synchr.Light Monitor	each	1	19056	SLC	19056
Toroid/Gap Monitor	each	2	1060	SLC	2120
Scrapers	each	2	7250	SLC	14500
misc. Materials	lot	1	2000	EU	2000
Total Materials					37676

*** LABOR ***	# of Units	Units MM	Total MM	Craft Code	Total Labor
Vacuum Engineer	1	2	2	ME	15440
Installation Labor	1	3	3	TV	19474
Total Labor					34914

Total 1.1.6.5	72590

6/16/87 ①
NLH

Cost Estimate for 3 Gev Vacuum Chambers (FY'26)
Excluding: Pumpout port / Junction Block / Bellows
BPM

Item#	Item Description	Qty/chamber	Mat'l Cost	Labor per Chamber	(32 chambers No Spares) Qty to Order	Total Mat'ls	Total Labor
1	4½"Ø Conflat Flanges	2 ea	$61.00	1 hr machinist @ 40/hr	64	3904	2560 machinist
2	Oval Flexure	6 ea	$5 (est)	—	192	960	
3	Tooling (Dies) for item 2	1 only	$5K (est)	—	1	5000	
4	Braze Flanges	14 ea	$10 (est)		448	4480	
5	Tooling (Dies) for item 4	1 only	$5K (est)		1	5000	
6	Rib Stampings	270	$0.50 ea (est)		8640	4320	
7	Tooling (Dies) for item 6	1 only	$5K		1	5000	
8	Thin Tubing (1.84"Ø)	8.5 ft	$15/ft	1.5 hr Machinist (Cut to length)	272 ft	4080	1920 Machinist
9	Brazing of Item 4 to thin tube segments + spot welding ribs together (Setup) + brazing ribs	6 segments	$100 (est. braze alloy)	Per piece: WLD: .5 hr BRZ: 1.0 hr setup	32×3 WLD @ 40/hr 32×6 BRZ @ 100/hr	3200 (alloy)	3840 welding 19200 braze setup
10	Furnace Run for brazing	1 run/chmbr (6 segments per run)	$500 charge for furnace run		32 runs	—	16000 furnace runs
11	Welding Oval flexures to braze Flanges	12 welds	—	3 hrs welder	96 hrs @ $40/hr	—	3840 welding
					subtotals	$35944 Mat'ls	$47360 fab. Labor

Mat'ls + Fab. Labor: $83,304
or approx. $83.3K

In addition: Design + Engineering (approx 10 drawings, checked etc ≃ 4 weeks, Plus approx 6 weeks vendor negociations over fabrication options, tooling design + prices, braze procedures etc)
— roughly $20K

Expedititer (approx. 3 man months @ ≈ $5K/month) ≃ $15K

Quick Estimate of Prototype additional costs: $22K

Summary: Engrg. + Design $20K
Expediting, Procurm't 15K
Fab (Mat'ls + Labor) 83K
$118K
with Prototype 22K
$140K

6/16/87 ②

Estimated Costs assuming Interatom builds chambers

Interatom Quote for 32 chambers 2 meters long:

$165 K

Actual Chambers are 2.4 meters long, so I assume Interatom price would increase by ($\frac{2.4}{2.0} = 120\%$) say 10%:

$\Rightarrow$ $181.5 K

Stanford Engineering + Design Staff work required to adequately specify, review, + negociate all details prior to and after award of contract: estimate approx. 6 weeks full time equivalent engineering + design, spread over a longer calender time, or approx. $12 K.

This brings Interatom quote to approx. $193.5K

If they have to change cross section, it is quite possible their quote could increase substantially.

6/16/87 ③

Prototype, if built by SSRL

2 or 3 segments only

(Oval flexure not easy to prototype due to tooling charges)

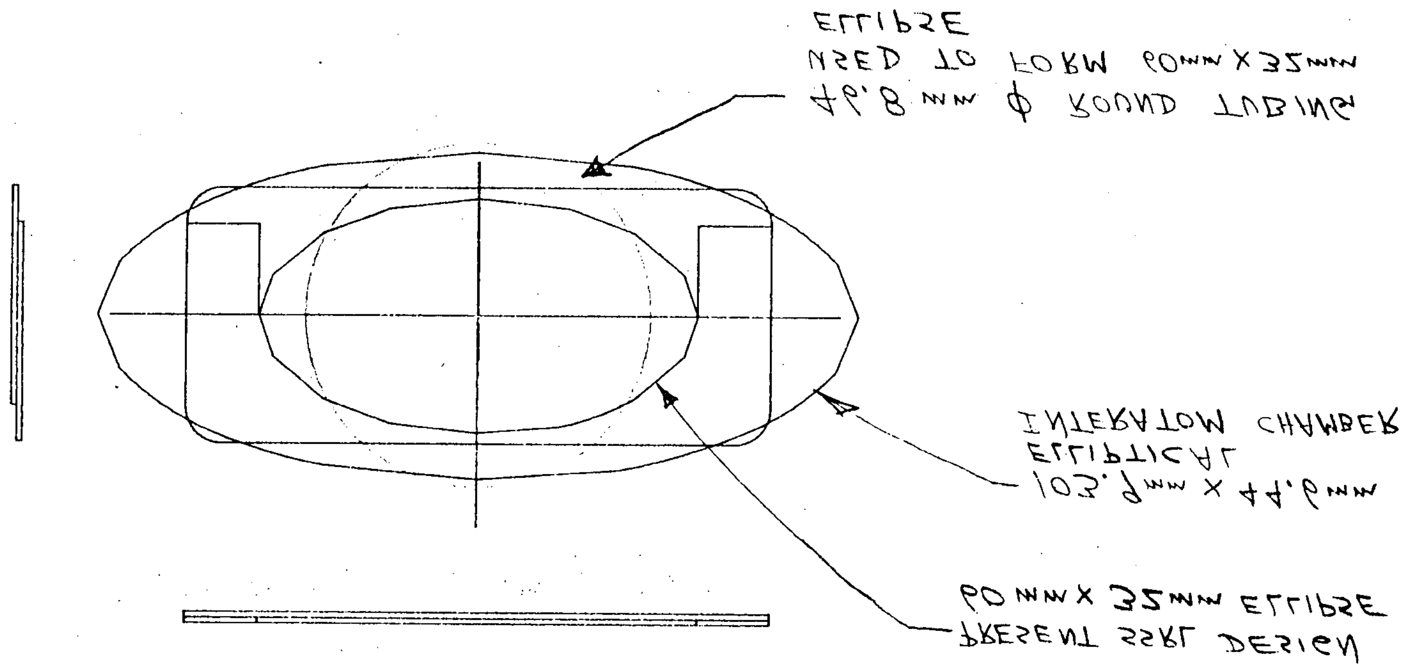
Drawings : 2 wks	$4K
Machining braze flanges	4K
Procurement, thin tubing	1K
Machining ribs	6K
Brazing	2K
Misc.	5K
	$22K

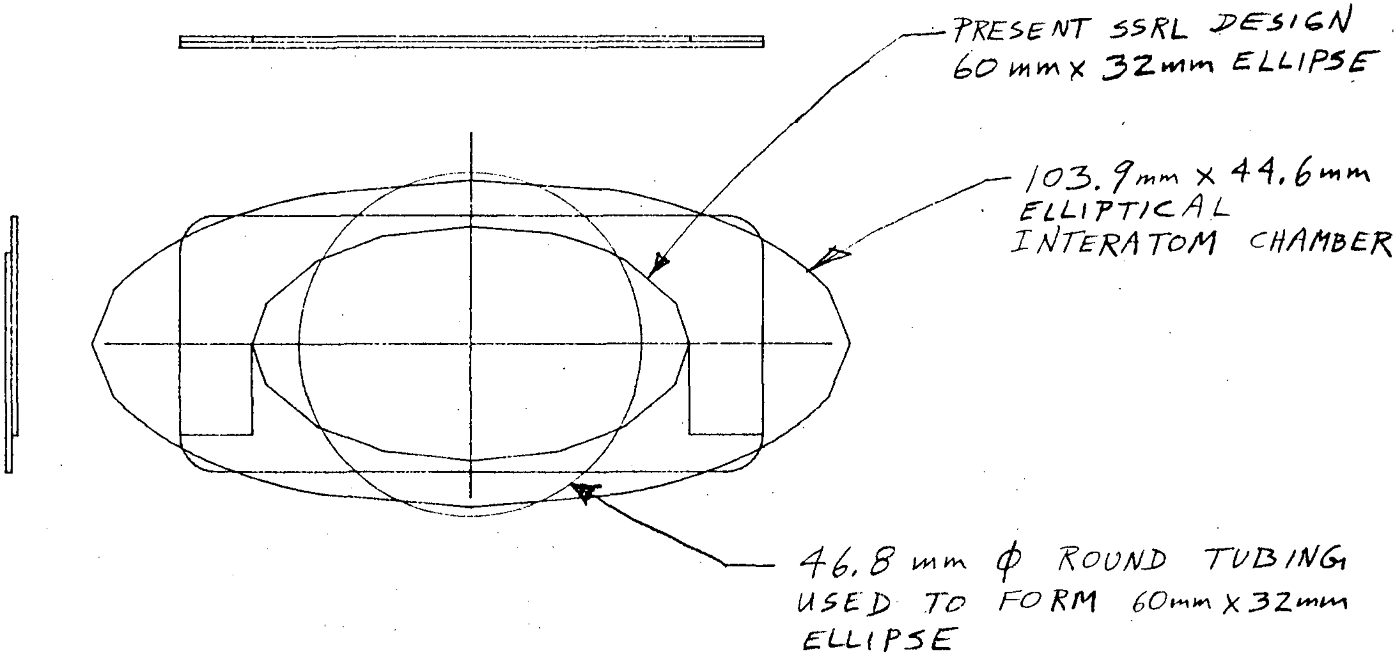
Best Guess Comparison

Interatom final quote plus Stanford interface ≈ $200K
(assuming they can make 32 x 60mm section)

Stanford costs for equivalent items, with prototype ≈ $150K

3RIBDET.DWG
SCALE: 1:1
6/16/87 NLH

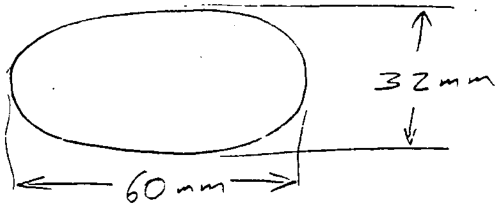




3RIBDET.DWG
SCALE: 1:1
6/16/87 NLH

4/8/87 ①

Review Vacuum Calculations for an assumed chamber Cross Sectional Shape:



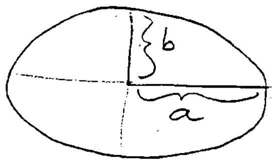
From Calculations found in my notes of 2/11/86 ("First Cost Estimate, 3 Gev Synchrotron for new SPEAR Injector, VACUUM SYSTEM"), for regularly spaced pumps (distance between pumps = $L_p \equiv 2L$, each pump having pumping speed S_p) in a long duct, the average of the parabolically-varying pressure is

$$\bar{P} = q_D B L \left(\frac{1}{S_p} + \frac{1}{3C} \right) \qquad (1)$$

where B = duct perimeter,
C = conductance of a length L of this duct,
q_D = outgassing rate (Torr-liter/sec cm^2)

For the latest version of the lattice (10/9/86), $L_p = 2.7872$ meters, $L = 1.3936$ m.

For the elliptical cross section above with



$a = 30$ mm
$b = 16$ mm

perimeter $B = 0.14697$ m $= 14.697$ cm
area, $A = .00147313$ m^2 $= 14.73$ cm^2

From Roth, p. 82

$$C \simeq 61.72 \frac{A^2 (A \text{ in cm}^2)}{B(\text{in cm})\, L(\text{in cm})} K \qquad (2)$$

where the factor K is assumed to be given by Table 3.5 p. 82 in Roth which is for a rectangle with ratio b/a. Here $\frac{b}{a} = \frac{16}{30} = .533$ and $K \simeq 1.146$

Then
$$C = \frac{61.72 (14.73)^2}{(14.697) L} (1.146) = \frac{1044}{L(\text{cm})} \ \ell/\text{sec} \qquad (3)$$
$$\equiv \frac{C_0}{L}$$

Substituting (3) into (1) ⇒

$$\bar{P} = q_D BL\left(\frac{1}{S_p} + \frac{L^{(cm)}}{3C_o}\right) \qquad (4)$$

This yields pressure in Torr provided L and B are expressed in cm, S_p in liters/sec, C_o is the dimensionless numerator (= 1044) of (3), and q_D is in (Torr-liters)/(sec cm²).

For the present design we are considering L = 139.36 cm, B = 14.697 cm, so

$$\bar{P}\,(\text{torr}) = q_D\left(\frac{T\text{-}l}{s\text{-}cm^2}\right)(2048)\left(\frac{1}{S_p} + \frac{1}{22.47}\right) \qquad (5)$$

For unbaked, degreased stainless steel (see Roth Fig 3.44) $q_D \approx 2\times10^{-9}$ t-l/sec cm², (which could be improved by electropolishing) (or baking),

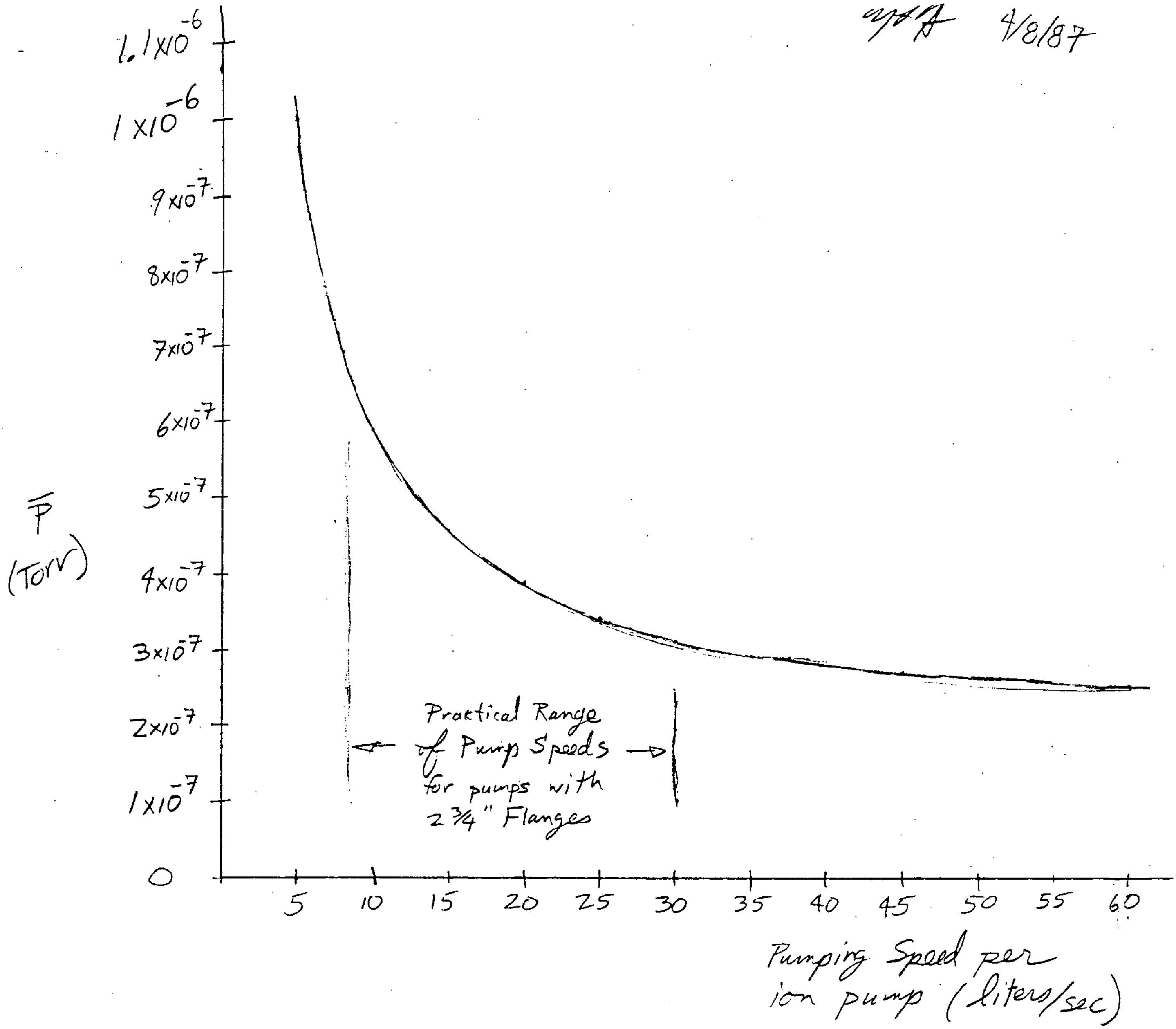
$$\bar{P} \simeq 4.10\times10^{-6}\left(\frac{1}{S_p} + \frac{1}{22.47}\right) l/sec$$

For various commonly-sized ion pumps, the resulting pressures would be:

S_p	Flange Size	$\bar{P}$ (Torr)
Perkin/Elmer, 11 l/sec	2 3/4"	5.55×10^{-7}
" 20 l/s	2 3/4"	3.87×10^{-7}
" 25	3 3/8"	3.46×10^{-7}
Varian 20 l/s	2 3/4"	3.87×10^{-7}
" 30 l/s	4 1/2"	3.19×10^{-7}
Varian Starcell 30 l/s	2 3/4"	3.19×10^{-7}
" " 45 l/s	4.5"	2.74×10^{-7}
Varian 8 l/sec	2 3/4"	6.95×10^{-7}
$S_p = \infty$		1.82×10^{-7} ← Minimum achievable for assumed outgassing rate

The benefits of going to $S_p > 20$ l/sec don't look that great. I would think we could live with 2 3/4" pumpout port flanges. This would still leave possible choices of 8, 11, 20, or 30 l/sec pumps.

4/8/87


1.1x10^-6
1x10^-6
9x10^-7
8x10^-7
7x10^-7
6x10^-7
5x10^-7
4x10^-7
3x10^-7
2x10^-7
1x10^-7
0
P̄ (Torr)
5
10
15
20
25
30
35
40
45
50
55
60
Practical Range of Pump Speeds for pumps with 2 3/4" Flanges
Pumping Speed per ion pump (liters/sec)

① of ④

4/13/87

Updated Cost Estimate for Vacuum Chambers

for 3.0 Gev Injector Synchrotron

- Based on proposed design as of 4/87
- Assumes 36 identical chambers (32 req'd plus 4 spares)
- Assumes $40/hr machinist + welder labor costs and $100/hr braze tech labor costs
- Assumes each chamber has a BPM
- Gives several options for ion pumping system, depending on desired average pressure vs. cost trade off.
- No Ceramic breaks are included at this time

CDR March 87

$ 422,491

Present Est.

	Vac. Chambers:	160K
	Pumping Syst:	19.6K roughing 95 K (Max) ion pumps + gate valves ; 60.7K (min)
unchanged	Pressure Monitoring:	10.7
	Installation	177K
		462.3K (Max), 428 K (Min)

Item Description	Qty per chamber	Mat'l Cost	Labor (per chamber)	(32 chambers + 4 spares) Qty to Order	Total Mat'ls	Total Labor
4½" Ø Conflat Flanges	5 ea ✓	$61 ea (CP)	—	180	10980	
BPM Elect. Feedthrus	4 ea ✓	$65 ea	—	144	9360	
2½" OD x .049 wall x 4" long SST Tubing	2 ea	$4	.1 hr Machinist	72	288	7.2 hr (MC) (machinist)
Junction Block	1 ea ✓	8 lbs SST @ $3/lb = $24	9 hr Machinist	36	864	324 hr (MC)
BPM internal parts	1 set	est. $20	20 hr machinist	36	720	720 hr (MC)
Bellows	1 ea	$200 (est)	—	36	7200	
Oval Flexure	6 ea	$5 est.	—	216	1080	
Tooling Charge (Dies) for	(non-recurring, 1-time)	$5K (est.)		1	5000	
Braze Flanges	14 ✓	$10 est		504	5040	
Tooling Charge (Dies) for	✓	$5K (est)		1	5000	
Rib stampings	270 ✓	$0.50 ea		9720	4860	
Tooling Charge for		$5K		1	5000	
Thin tubing	8.5 ft @ ✓	$15/ft	1.5 hr machinist (cut to lengths) per chamber	306 ft	4590	54 hr (MC)

Brazing BPM parts	1	—	1 hr (BZ) ✓	36		36hr (BZ)
Brazing flanges + Ribs to thin tubes	6	100 (est) Braze alloy	12 hr (BZ) ✓	36		432hr (BZ)
Welding Ports, Flanges, + bellows to Junction Block	1	—	1.75 hr (WLD)	36		63hr (WLD)
Welding BPM	1	—	1.5 (WLD) ✓	36		54hr (WLD)
Welding oval flexures	12	—	3.0 ✓	36		108hr (WLD)

Tot, Matls: 59,982
Total Labor: 100,008
$ 159,990

MC: 1105.2hr @ $40/hr = 44208
BZ: 468 hr @ $100/hr = 46800
WLD: 225 @ $40/hr = 9000
100,008

Ion Pumping System (Section 5.2.2)

	Description	Units	# units	unit cost	Cost Base (1986 price)	Total	$\bar{P}$ (Torr)
Either :	8 l/sec ion pump	ea	36	735	(CP)	38,940	7×10^{-7}
	4½ - to 2¾ reducing flange	ea	36	80	(CP)		
	Medium Pump Supplies	ea	6	1600	(CP)		
OR :	20 l/s ion pump	ea	36	1330	(CP)	69960	3.9×10^{-7}
	4½ - to - 2¾ reducing flng	ea	36	80	(CP)		
	Medium Pump Supplies	ea	12	1600	(CP)		
OR :	30 l/s ion pump	ea	36	1500	(CP)	73200	3.2×10^{-7}
	Medium Pump supplies	ea	12	1600	(CP)		
plus	Gate Valves (VAT series 58 all-metal 88mm ID Gate valve w/RF contact) (Cat.# 58039-CE44)	ea	2	10900	(CP)	21800	

Subtotals : \$ 60740 for 8 l/sec (7×10^{-7} Torr)
or 91760 " 20 l/sec (3.9×10^{-7})
or 95000 " 30 l/s (3.2×10^{-7})

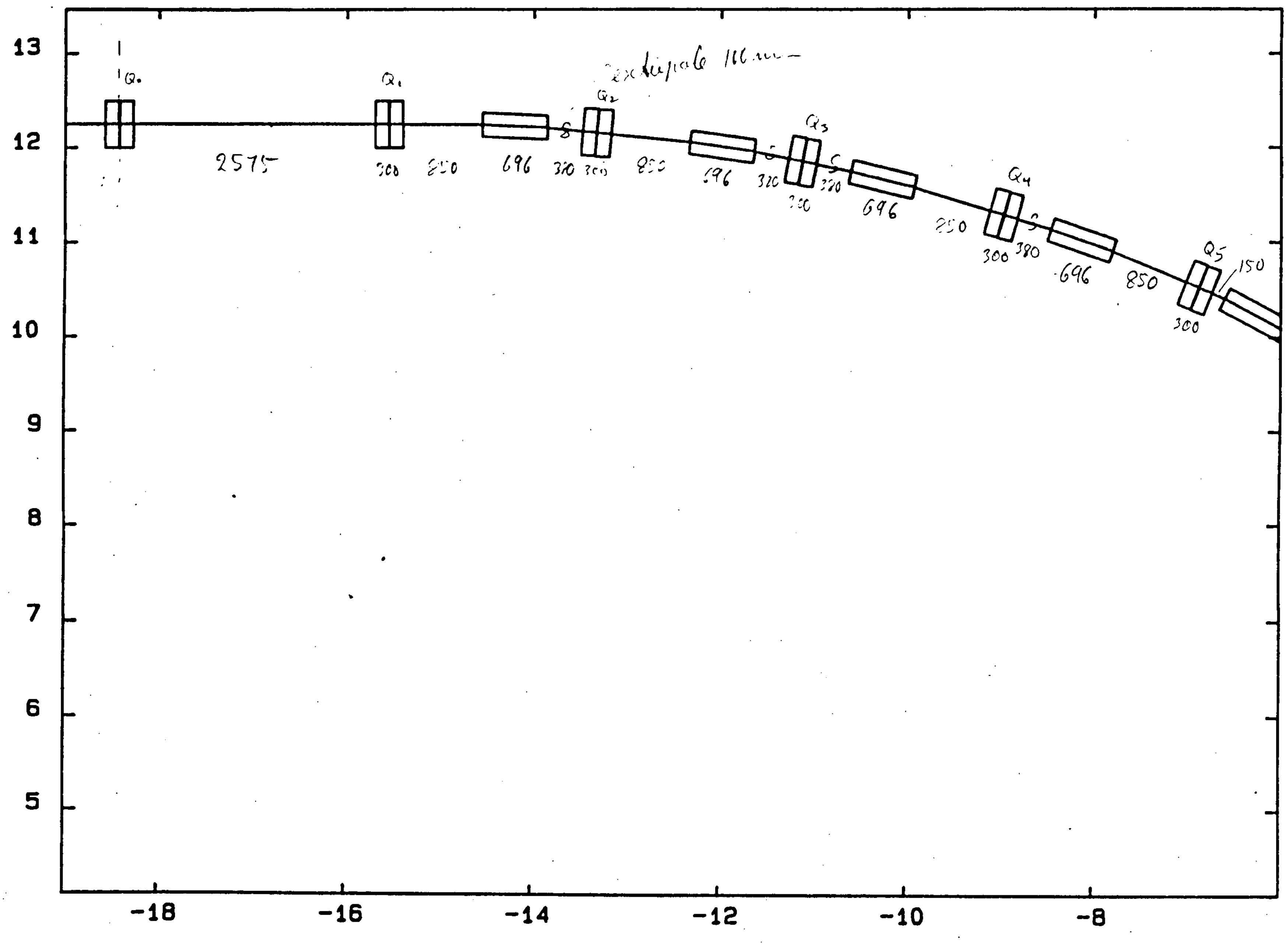
plus	400 l/s ion pump	ea	1	9280	(CP)	= 11,125 (This might be in RF system budget)
	+ supply for RF cav.	ea	1	1845	(CP)	

First Cost Estimate

3 GeV Synchrotron for new SPEAR Injector

Vacuum System

Prepared by N. Hower, SSRL
2/12/86



Sextupole 110 mm
Q0
Q1
Q2
Q3
Q4
Q5
S
2575
300
850
696
320
300
850
696
320
300
320
696
850
300
380
696
850
300
150
13
12
11
10
9
8
7
6
5
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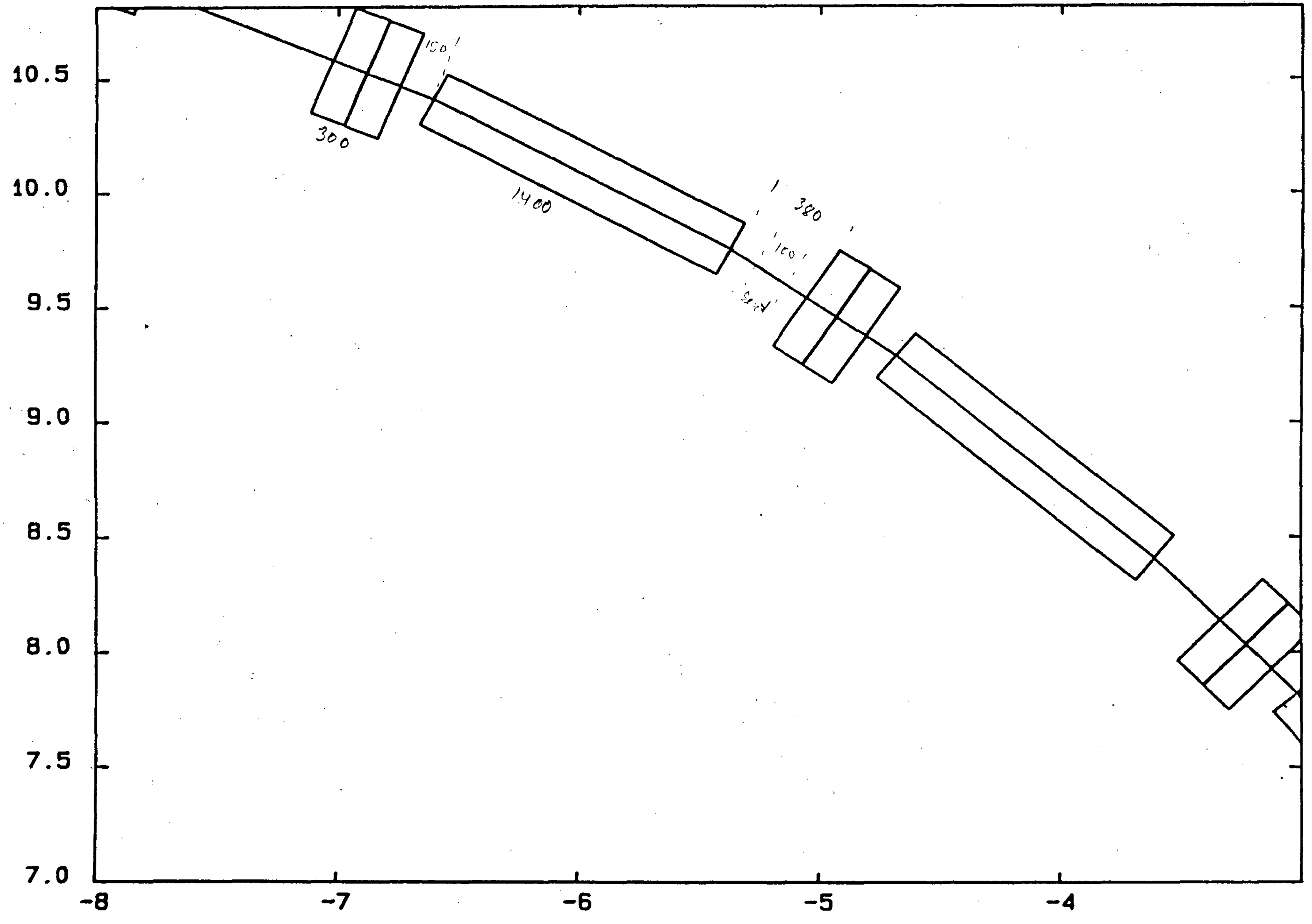
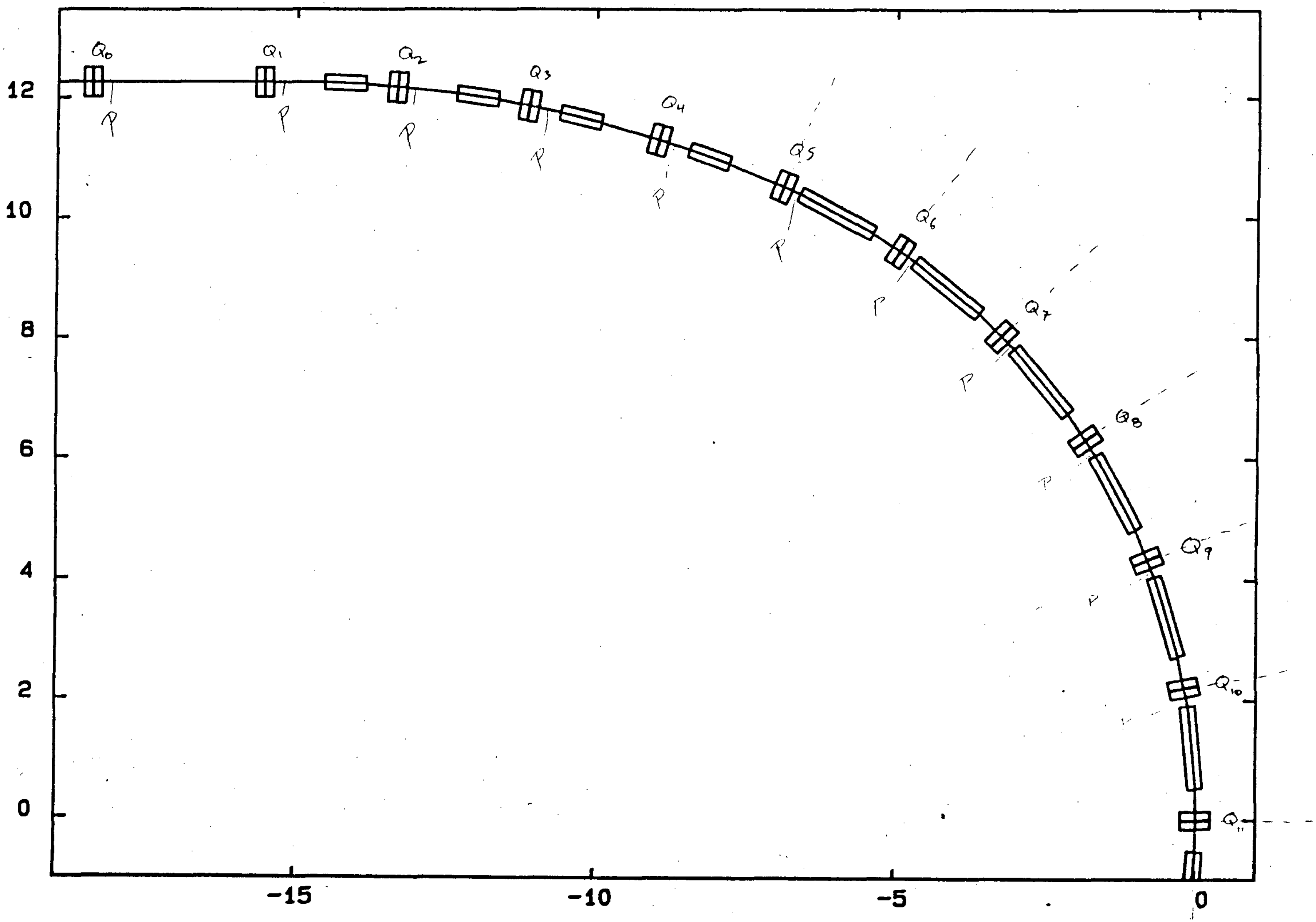
-16
-14
-12
-10
-8

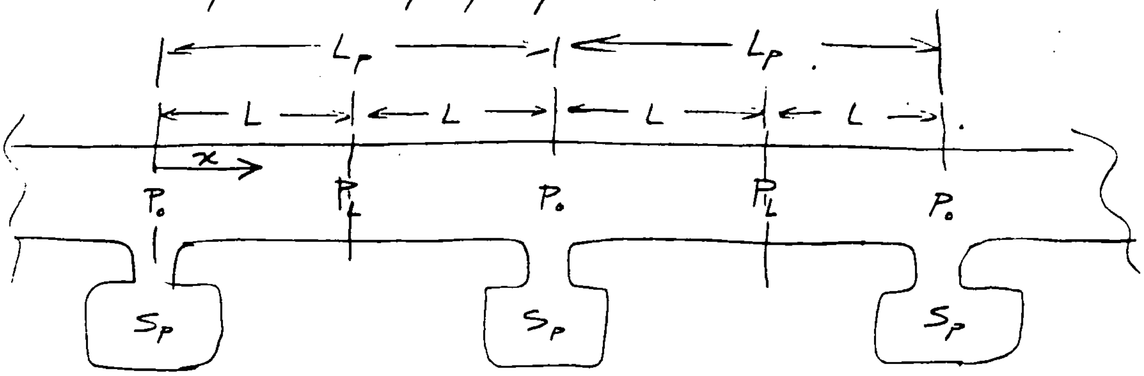


10.5
10.0
9.5
9.0
8.5
8.0
7.5
7.0
-8
-7
-6
-5
-4
300
150
1400
380
150


Q0
Q1
Q2
Q3
Q4
Q5
Q6
Q7
Q8
Q9
Q10
Q11
P
12
10
8
6
4
2
0
-15
-10
-5
0

	Element	Length	
	$\frac{1}{2}$ Q_0	150 mm	2.725
	D	2575	
	Q_1	300	
	D	850	
	B	696	2.226m
	D	140 (5.51")	
	S	100	
	D	140	
	Q_2	300	
	D	850 (33.46")	
	B	696	2.226m
	D	140	
	S	100	
	D	140	
	Q_3	300	
	D	140	
	S	100	2.226m
	D	140	
	B	696	
	D	850	
	Q_4	300	
	D	140	
	S	100	2.226
	D	140	
	B	696	
	D	850	
	Q_5	300	
Repeats 6 times in Quartic Ring (Total 53.52m of these cells)	D	150 (5.91")	
	B	1400	2.23m
	D	140	
	S.	100	
	D	140	
	Q_6	300	

Consider a periodically-pumped duct:



From Roth, Vacuum Technology (North-Holland, 1976) p. 129,

$$P(x) = q_D B\left[L/S_p + \frac{x}{C} - \frac{x^2}{2CL}\right] = P_o + q_D B\left[\frac{x}{C} - \frac{x^2}{2LC}\right]$$

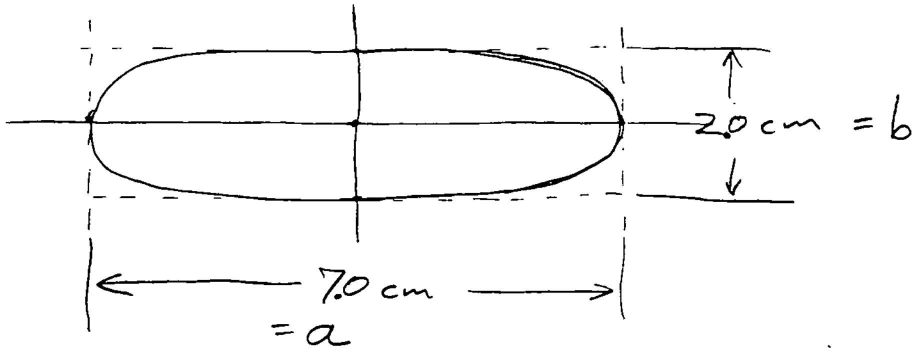
$$P_o = q_D B L/S_p$$

$$P_L = q_D B L\left[\frac{1}{S_p} + \frac{1}{2C}\right]$$

$$P_L - P_o = \frac{q_D B L}{2C}$$

in which q_D = outgassing rate (Torr-liter/sec cm^2)
C = Conductance of a pipe of length L
S_p = pump speed
B = duct perimeter

The cross-section is approximately elliptical, 20mm x 70 m
as shown:



I take as a first approximation the conductance of this tube to be about that of a rectangular cross section of dimensions a & b, for which (Roth p. 52) for $b/a = 0.286$ ($K \simeq 1.23$)

$$C_{air} = 38.0\,\frac{a^2b^2}{(a+b)L} \quad \text{liter/sec}$$

where a, b, & L are in cm.

For $a \simeq 2$ cm, $b \simeq 7$ cm, this yields

$$C_{air} \simeq \frac{828}{L\,(\text{cm})} \text{ liter/sec}$$

(Thus a 1 meter length has conductance of 8.28 l/sec).
16.76

The average pressure is

$$\overline{P} = \frac{1}{L}\int_0^L P(x)\,dx = \frac{1}{L}\left\{ P_0 L + \frac{q_D B}{C}\left[\frac{L^2}{2} - \frac{L^{\cancel{3}\,2}}{2(3)\cancel{L}}\right]\right\}$$

$$= P_0 + \frac{q_D B L}{3C}$$

$$= \frac{q_D B L}{S_p} + \frac{q_D B L}{3C} = q_D B L\left(\frac{1}{S_p} + \frac{1}{3C}\right)$$

In the arc portions of the ring, the cells repeat in units of 2.23 meters long. <u>Suppose we place one pump every cell</u>, so $L_p = 2L = 2.23$ m and $L = 1.115$

Then $\overline{P} = q_D \; 2(a+b)\, L\left(\frac{1}{S_p} + \frac{1}{3\left[\frac{828}{L}\right]}\right)$

$$= q_D\,(2)(9\text{ cm})(111.5\text{ cm})\left[\frac{1}{S_p} + \frac{111.5}{3(828)}\right]$$

$\frac{1}{22.28}$

$$= 2007\left(\frac{1}{S_p} + \frac{1}{22.28}\right) q_D .$$

A minimum requirement on $\overline{P}$ is that $\overline{P} \lesssim 10^{-6}$ Torr, althoug this leaves little conservatism. Assuming $\overline{P} \simeq 10^{-6}$ Torr and $q_D \simeq 2\times10^{-9}$ Torr-liter/sec cm^2 (See Roth p. 142 - this is a median value for clean, degreased stainless steel, <u>not</u> <u>baked</u>.) leads to

$$S_p \simeq \frac{1}{\overline{P}/2007\,q_D - \frac{1}{22.28}}$$

$$\simeq 4.9 \text{ liter/sec.}$$

Notice that because of the conductance-limited nature o this cross-section, the minimum average pressure which could ever be reached using one pump per 2.23 meter cel with $S_p = \infty$ and $q_D \simeq 2\times10^{-9}$ T-l/sec cm^2 is $\underline{\overline{P}_{min} \simeq 1.80\times10^{-7}}$ T

We can summarize the results thus far in the following table, where it is assumed that $q_D \simeq 2\times10^{-9}$ Torr liter/sec cm^2 and that there is one pump per cell (of length 2.23 m):

	S_p (liter/sec)	$\overline{P}$ (Torr)	P_o (Torr) $= \frac{q_D B L}{S_p}$ (at the pump)	Pump Lifetime (approx.)
	∞	1.8×10^{-7}	0	∞
Varian #1330	20 ℓ/sec	3.8×10^{-7}	2.0×10^{-7}	20 years
Varian #735	8 ℓ/sec	6.8×10^{-7}	5.0×10^{-7}	9.1 years
	4.9 ℓ/sec	1.0×10^{-6}	8.2×10^{-7}	
Varian #500	30 ℓ/sec	3.14×10^{-7}	1.34×10^{-7}	30 years

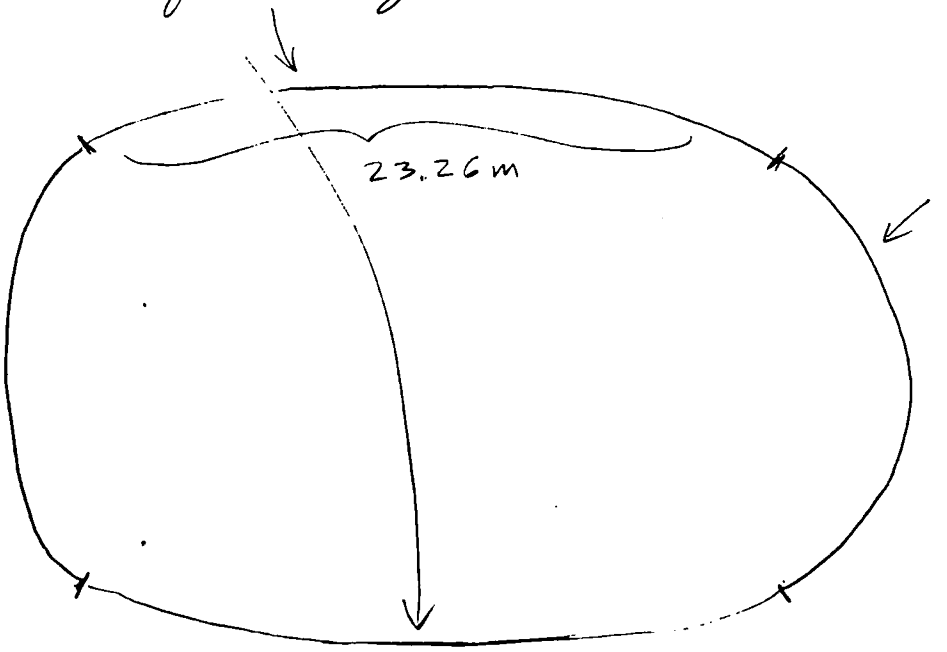
If we put one pump in every alternate arc cell, $L = 2.23$ m in the previous results and the minimum achievable average pressure would be (for infinitely-fast pumps)

$$\overline{P}_{min} \simeq (2\times10^{-7})(2)(9)(223.0)\left\{\frac{1}{\infty} + \frac{223}{3(828)}\right\} \simeq 7.2\times10^{-7}\ \text{Torr},$$

(for one pump every 2 cells)

while using, say, 20 ℓ/sec pumps would give $\overline{P} \simeq 1.12\times10^{-6}$ Torr. Thus the omitting of every other pump would probably lead to unsatisfactorily high pressures.

What about in the remainder of the ring (i.e., in the "flatter" regions:



These 2 end regions comprise ≃ 53.5 meters of circumference

In examining the lattice dimensions on pg 1 above, the cells of 2.226 m length are almost the same length (2.230 m) as those previously considered. While there appear to be more open areas to mount pumps in the "flat" regions, if the vacuum chamber cross section remains the same 20 × 70 mm area, the conductance limitation will still exist and the pumping requirements will remain as found above.

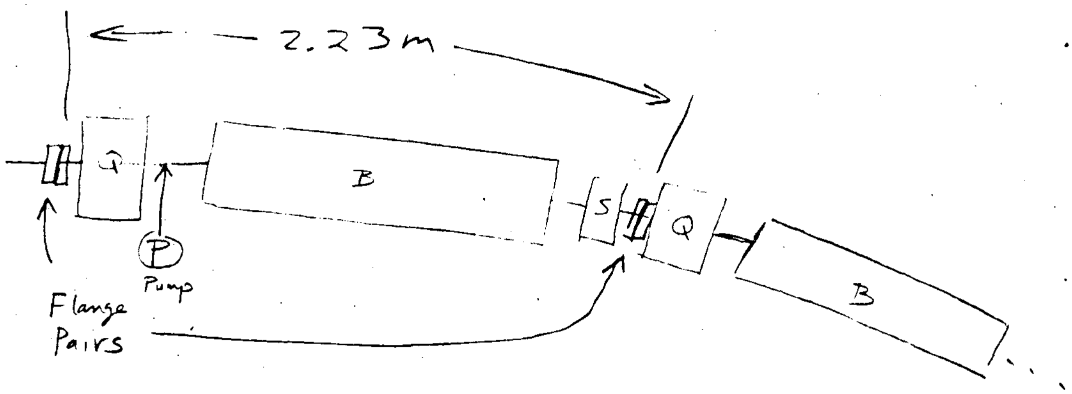
As a first-cut design therefore we propose a system of nearly equally-spaced pumps at intervals of about 2.23 meters. The number of pumps would be approximately 100m/2.23m ≃ 45 pumps. One could
use 20 l/sec pumps giving $\bar{P} \approx 3.8 \times 10^{-7}$ Torr ($60K for pumps
or 8 l/sec pumps giving $\bar{P} \simeq 6.8 \times 10^{-7}$ Torr ($33K for pumps
or 30 l/sec pumps giving $\bar{P} \simeq 3.1 \times 10^{-7}$ Torr ($67.5K for pum

Synchrotron Radiation Heating of the wall of the vacuum chamber can be shown to be quite negligible, so no cooling is anticipated for the vacuum system.

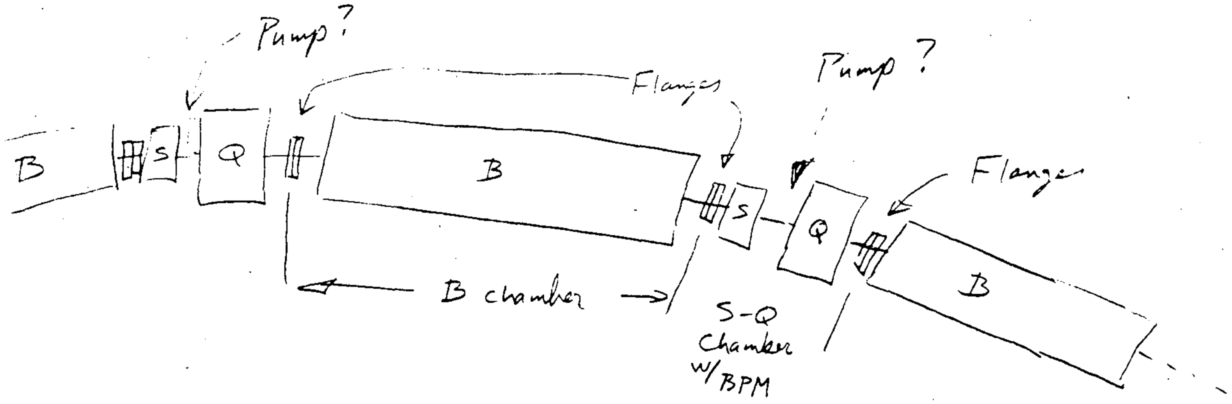
<u>Items to cost:</u>

I. Pumps (see above)
II. Matls + Labor to fabricate chambers
✓ III. Sector Valves (to isolate ring into 2 or 4 sections)
✓ IV. Beam Position Monitors (Included in)
✓ V. Roughout System
✓ VI. Pump Power Supplies
✓ VII. Misc. Valves + Vacuum Hardware
✓ VIII. Pressure Monitoring Devices

Option A



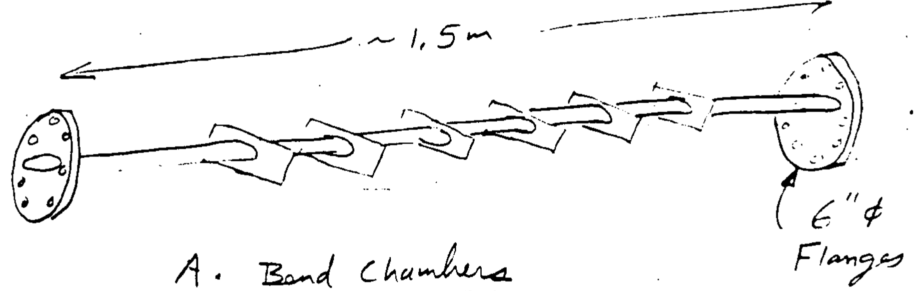
Option B



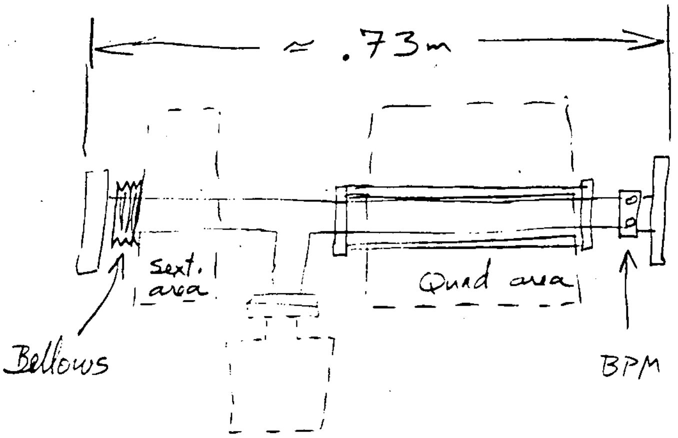
Pro: Shorter chambers to handle

Con: Extra flange pair uses up space possibly needed for pumpout ports.

Consider Option B:



A. Bend Chambers



B. Sextupole/Quadrupole Chambers

Estimates:

A. Bend Chambers:

2 ea 6"ϕ Flanges @ $75 ea = 150
1 boltset @ $35 = 35
Tubing, thin @ $15/ft ≃ 75
Reinforcing rib stampings 15 ea @ $5 ≃ 75
subtot, mat'ls 335
Labor: 8 hrs welding, Brazing @ $50/hr = 400
6 hrs machining @ $50/hr = 300
sub, labor 700
Total, Bend Chambers ≃ $ 1.035 K, ea

B. Sextupole/Quadrupole Chambers

2 ea 6"ϕ Flanges @ $75 = 150
1 ea bolt set @ 35 = 35
Tubing @ $15/ft = 35
Special Stiffeners (not designed) ≃ 100
BPM Feedthrus 4 @ $65 = 260
Bellows 1 ea @ ≃ 200 200
$780 mat'ls

Labor : Machining: (BPM parts, bellows rings, special stiffeners etc)

Estimate 20 hrs @ $50 =	1000
Brazing/welding : 10 hrs @ 50	500
	1500 labor

Total, sextupole/Quadrupole chambers : $2.28 K ✓

Total : 1.035K + 2.28K = $3.32 K

overall length : 2.23 m

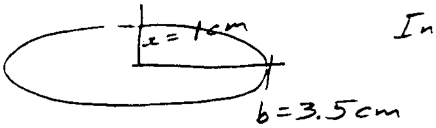
Estimated cost/meter ≈ 1.49 K , say $1.5K/meter

∴ For 100 meter circumference , allow approx $150K

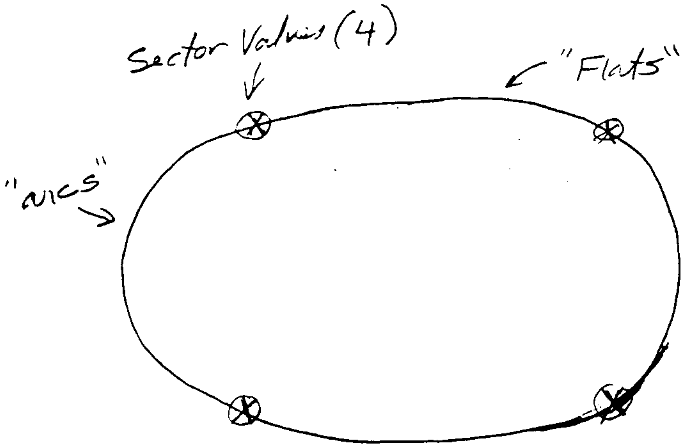
V. Roughout System

Starting Pressure Req'd : 1×10^{-3} Torr (or slightly greater)

Total Internal Volume : $V = \pi a b L \simeq 110$ liters.

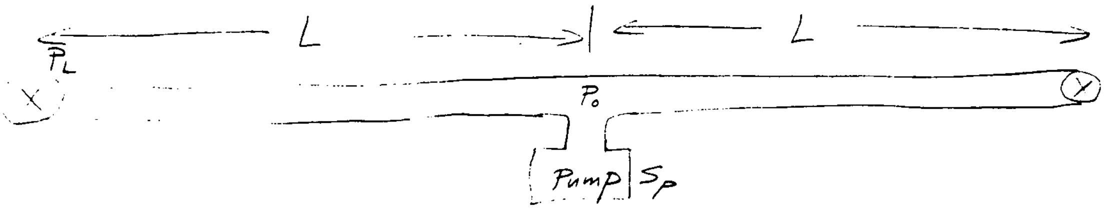


Including ion pumps + Misc, lets say $V_{total} \simeq 120$ liters.



Assume each of the 4 sectors is about equal in volume ($\simeq$ 30 liters), length ($\simeq$ 25 meters), and conductance, and that we rough out each section separately.

Try one roughout port/sector:



Here $L \simeq 12.5$ m

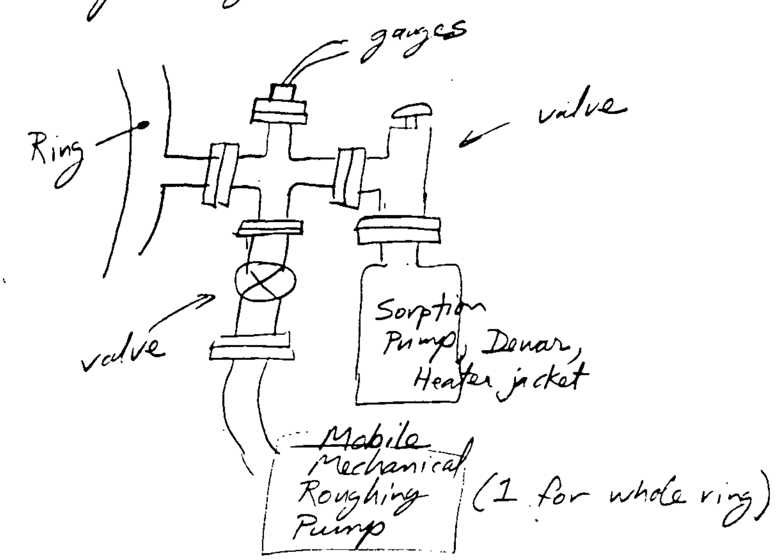
$$P_L = q_D B L \left[\frac{1}{S_p} + \frac{1}{2C} \right]$$

$$P_{L_{min}} = \frac{q_D B L}{2C} = \frac{q_D B \cdot L^2}{2(828)} = \frac{(2 \times 10^{-9} \frac{T\text{-}l}{sec\, cm^2})(18cm)(1250cm}{2(828)}$$

$$= 3.4 \times 10^{-5} \text{ Torr}$$

This should be good enough to start the ion pumps. The total gas load is 760 Torr x 30 liter = 23000 Torr-liters, well below the 170,000 Torr-liter pumping capacity of a double sized Varian Vacsorb pump.

The proposed roughout system would thus consist of the following



Costs:

4ea - Cross, 2 ¾" Flanges @ $113 ea = $ .452 K

4ea - Double Vacsorbs Varian P/N 941-6502 @ $897 ea = 3.59 K
4ea - LN_2 Dewar for ↑, P/N 944-0012 @ 920 = 3.68
4ea - Heating Band P/N 944-0045 @ 245 = 0.98
4ea - GP Series 275 Convection Gauge System @ 481 = 1.92
Model 275094

8ea - Varian P/N 951-5092 1½" @ 799 = 6.39
Hand operated Right Angle Valves

1ea - Mobile Mechanical Pump (Varian SD-700) @ 2350 = 2.35

$19.36 K

Say $20 K

III. Sector Valves: Assume 4 ea GP valves (or equiv. radiation-resistent all-metal valves) @ $10K ea = $40K

VI. Pump Power Supplies

A more economical system might be possible to design, but due to the fairly high operating pressures & starting pressures, I will assume that 1 medium power supply (Varian P/N 921-0062 @ $1600 ea) is req'd for every three ion pumps, for a total of $\frac{45}{3} = 15$ units

Total: $24 K

VIII. Pressure Monitoring Devices

Assume	8 ea	Model 580 Nude ion gauge (Varian) @ $319	= $ 2.55 K
	8 ea	2¾" Tee's @ $ 90	= .72
	8 ea	Varian Model 843 Ion Gauge & TC Gauge Controller @ 875	= 7.00
	8 ea	Model 531 TC Gauge @ $148	= .38
		Total	$ 10.65K

VII. Misc. Valves & Hardware

Estimate approx $ 20 K for as-yet-unspecified hardware.

YZH 4/2/86

Cost Summary - Vacuum System for 3 GeV Injector Synchrotron

Category	Description	Estimated Cost
1	Mat'l + Fab. Labor for fabricating thin-walled vacuum system, 100 m total length (see pp. 6, 7, 8), including BPMs.	$ 150.0 K
2	Sector Valves (see p. 10)	40.0
3.	Roughout System (see pp 9 + 10)	20.0
4.	Pressure Monitoring Equipment (p. 11)	11.0
5.	Misc. Valves + Vacuum Hardware (p. 11)	20.0
6.	Ion Pump Power Supplies (p. 10)	24.0
7.	Ion Pumps - 45 pumps Assuming 20 l/sec pumps ($\bar{p} \simeq 4 \times 10^{-7}$ Torr) Alternate: 8 l/s pumps ($\bar{p} \simeq 7 \times 10^{-7}$ torr)	 60.0 or (33.0)
		$ 325 K (or $298K using 8 l/sec pumps)

SCIENTIFIC INTERNATIONAL INC.

P.O. Box 143
Princeton, N.J. 08542
Tel. (609) 924-3011

June 4, 1987

Professor Helmut Wiedemann
Applied Physics Department
Stanford Synchrotron Radiation Laboratory
Bin 69 - Box 4349
Stanford, CA 94305

Reference: Thin-walled Ribbed Beam Pipes

Dear Professor Wiedemann:

Pursuant to our previous discussions regarding your potential need for **thin-walled ribbed beam pipes**, and yesterday's verbal telephone offer, we are now able to confirm our offer as follows:

QUANTITY OF 32 CHAMBERS,

ELLIPTICAL CROSS-SECTION -

Wall thickness: 0.3 mm

Height of Chamber: 44.6 mm

Width: 103.9 mm

Length: 2 meters, each Chamber

Material: TP 321

Number of ribs per Chamber: 92

One vacuum flange at each end of Chamber

Final design according to SLAC specifications

Manufacturing of one prototype

Leak testing

Tooling

PRICE: **Approximately $165,000.00 f.o.b. Princeton, New Jersey.**

A vacuum bakeout is not included in the above monetary value.

Continued . . . .

We must stress that our given price only presents an **approximate** value, since the detailed specifications are not known at this time. This price is also based on the current $-DM exchange rate. However, we included in our calculations 8.7% Import Duty; SLAC can legally be exempted from these latter charges according to Customs Regulation **Item 851.60**, provided an application for exemption is filed PRIOR to importation of goods.

We hope to have given you adequate information at this point, and we would be delighted to pursue some further discussions in reference to your particular needs.

Sincerely,

Hans D. Gerwers

HDG/bb

SCIENTIFIC INTERNATIONAL INC.

P.O. Box 143
Princeton, N.J. 08542
Tel. (609) 924-3011

2-26-87

CC WINICK
YOUNGMAN
WIEDEMANN
GOULD
BICKNELL
MORALES

February 25, 1987

Mr. Richard Boyce
STANFORD LINEAR ACCELERATOR CENTER
P.O. Box 4349
Bin 69
Stanford, CA 94305

Reference: Elliptical-Shaped, Thin-Walled Beam Pipes

Dear Richard:

Pursuant to our several preliminary discussions regarding **Elliptical-Shaped, Thin-Walled Beam Pipes**, we include herewith some Xerox copies of similar chambers which have been built by the European INTERATOM CORPORATION, a 100-percent daughter company of SIEMENS AG, the latter being a company with over 35 billion dollars in annual sales volume. SCIENTIFIC INTERNATIONAL, INC. is the official U. S. Representative for INTERATOM.

The Beam Pipes, delineated in the photocopies, have a wall thickness of 0.3 millimeters and are manufactured from Stainless Steel. The use of INCONEL material is also possible. INTERATOM recommends, based on their experience, the incorporation of heater elements into the Beam Pipe structure. Such elements can be brazed directly to the Chamber Ribs. The degassing rate of the ribbed beam tubes is in the range of:

equal/less than 10^{-13} mbar x liters/second.

The final vacuum in those Chambers can be maintained at:

equal/less than 10^{-11} mbar.

INTERATOM presently builds such Chambers for **CERN** in Geneva, Switzerland, and **GSI** in Darmstadt, West Germany. For the latter facility, the ribbed beam tubes will be installed in magnets whose fields will vary a few Teslas a second. The ribbed tubes are designed to withstand at least 25 Situ heating intervals over a 24-hour period, at 300° Celsius, without damage.

Without being bound to the following price level, the cost for such structures is likely to be around **$3,000 per meter**, without Import Duty. As mentioned on previous occasions, SLAC can legally be exempted from Import charges, provided that an application is filed **before** importation of goods. Please consider the price above as a ballpark figure only.

Continued . . . .

Please take the enclosed information only as a starting point for futher discussions. INTERATOM will exhibit some sample Chambers during the upcoming IEEE Particle Accelerator Conference in Washington; SCIENTIFIC INTERNATIONAL was informed that the possibility exists for a visit by INTERATOM Personnel to your facility, following the IEEE Conference, if you should so desire.

We look forward to hearing from you in this regard in the near future.

Sincerely,

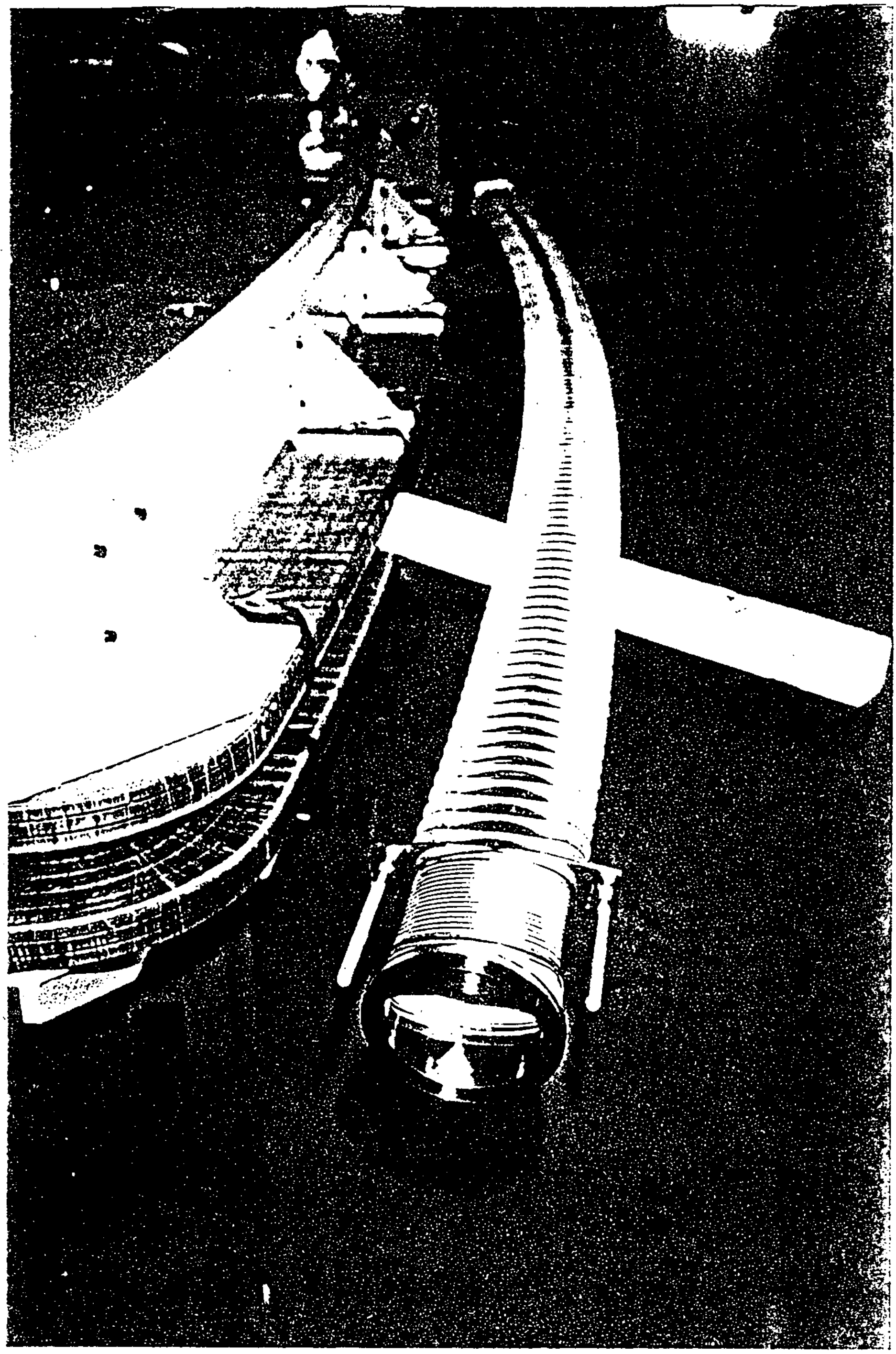
Hans D. Gerwers

HDG/bb

Enclosures

SCIENTIFIC INTERNATIONAL INC.
P.O.Box 143
Princeton, N.J. 08542
Tel. (609) 924-3011

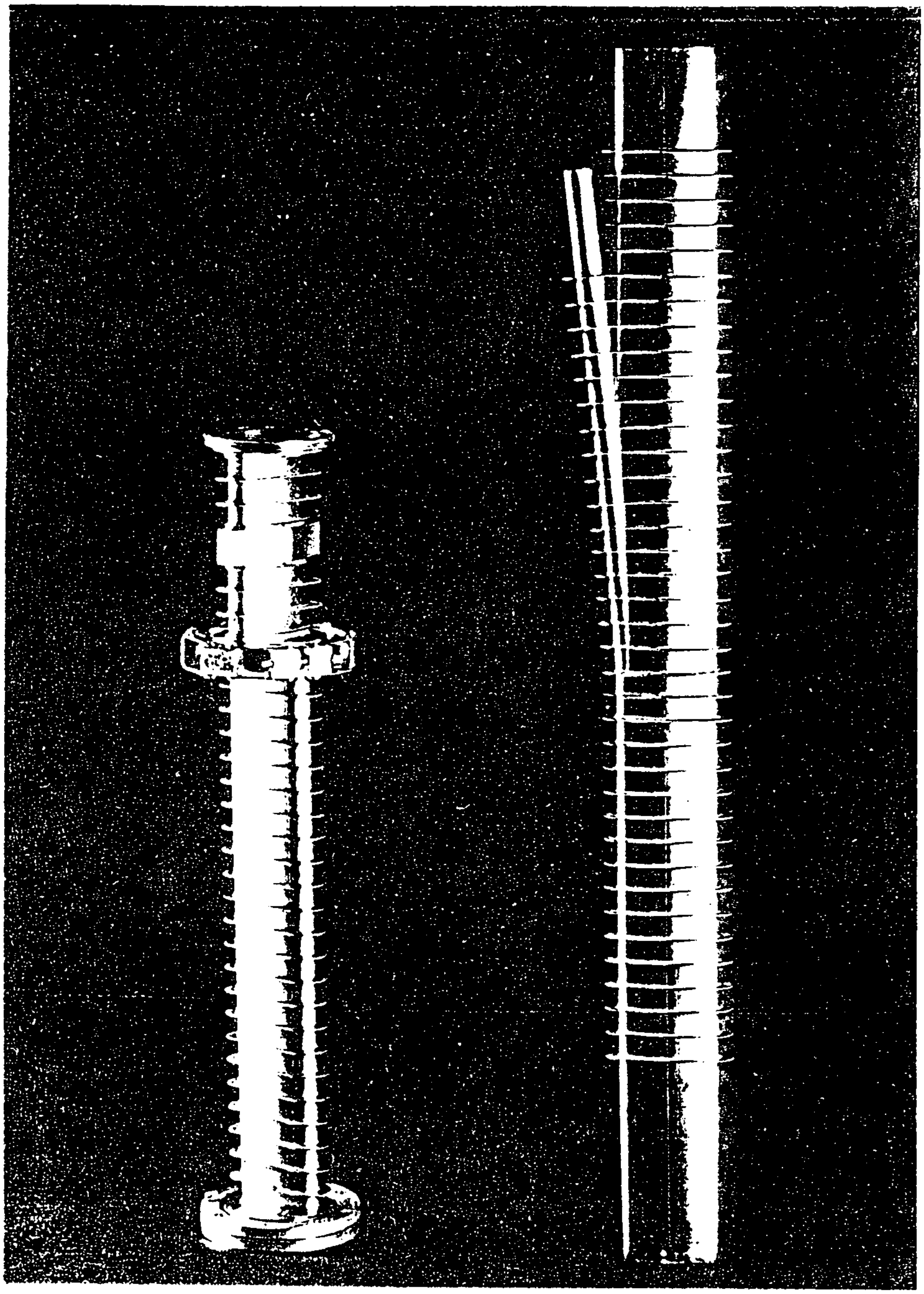
Interatom GmbH



Ribbed Magnetic-Vacuum-Chambers
for Accelerator Plant "ELSA"
University Bonn

SCIENTIFIC INTERNATIONAL INC.

P.O.Box 143
Princeton, N.J. 08542
Tel. (609) 924-3011



"Magnetic-Vacuum-Chambers
for Accelerators"

1.1.7 RF SYSTEM

1.1.7.0 E D & I

*** LABOR ***	# of Units	Units MM	Total MM	Craft Code	Total Labor
Electr. Engineering	1	12	12	EE	91625
Mech. Engineering	1	2	2	ME	15440
Mechanical Designer	1	2	2	MD	10975
Electrical Designer	1	6	6	ED	32924
Coordinator	1	12	12	CS	63045
Documentation Clerk	1	6	6	DC	16469
Total Labor					230477
Total 1.1.7.0					230477

1.1.7 RF SYSTEM

1.1.7.1 RF Power Source

1.1.7.1.1 Klystron Assembly

*** MATERIALS ***	Unit	# of Units	Unit Cost	Cost Base	Total $
Klystron	set	1	130000	SLAC	130000
Klystron Focus Magnet	set	1	3000	EU	3000
Klystron Temp. Mon.	set	1	340	SP86	340
Water Rack & Hose	set	1	4120	SP86	4120
misc.Klystron Services	set	1	4480	SP86	4480
Klystron Focus Control	set	1	5900	SP86	5900
Klystron Monitor Panel	set	1	14150	SP86	14150
Contract Labor	hr	693	JL	SP86	12440
Total Materials					174430

*** LABOR ***	# of Units	Units MM	Total MM	Craft Code	Total Labor
RF Engineer	1	1	1	EE	7635
RF Technician	1	1	1	TE	4246
Total Labor					11881
Total 1.1.7.1.1					186311

1.1.7 RF SYSTEM

1.1.7.1 RF Power Source

1.1.7.1.2 HV Supply

*** MATERIALS ***	Unit	# of Units	Unit Cost	Cost Base	Total $
HV Power Supply (refurb.)	each	1	12000	VQ86	12000
HV Box/Crow Bar	each	1	7380	SP86	7380
AC Contacter	each	1	5000	SP86	5000
Installation/Mat.	each	1	3100	SP86	3100
Contract Labor	hr	550	JL	SP86	9873
Total Materials					37353

*** LABOR ***	# of Units	Units MM	Total MM	Craft Code	Total Labor
RF Engineer	1	1	1	EE	7635
RF Technician	1	1	1	TE	4246
Total Labor					11881
Total 1.1.7.1.2					49234

1.1.7 RF System

1.1.7.2 RF Cavity

*** MATERIALS ***	Unit	# of Units	Unit Cost	Cost Base	Total $
prep.Cavity (SLAC Surpl.)	set	1	10000	SP86	10000
Tuner Motor	set	1	10660	SP86	10660
Misc. Support Materials	set	1	5000	EU	5000
Waveguides	set	1	26800	VQ86	26800
Contract Labor	hr	447	JL	SP86	8024
Total Materials					60484

*** LABOR ***	# of Units	Units MM	Total MM	Craft Code	Total Labor
RF Engineer	1	1.0	2	EE	15271
RF Technician	1	1.0	1	TE	4246
Mechanical Engineer	1	1.0	1	ME	7720
Total Labor					27237

Total 1.1.7.2	87721

1.1.7 RF System

1.1.7.3 Drive System

*** MATERIALS ***	Unit	# of Units	Unit Cost	Cost Base	Total $
Tuner Control	each	1	13000	SP86	13000
Low Level Electronics	set	1	22500	SP86	22500
Misc. Instrumentation	set	1	40000	SP86	40000
Controls/Interface	set	1	28400	SP86	28400
Power Meter System	set	1	9800	SP86	9800
Control Cabling	set	1	1250	SP86	1250
Relays etc.	set	1	7300	SP86	7300
Contract Labor	hr	1744	JL	EU	31307
Total Materials					153557

*** LABOR ***	# of Units	Units MM	Total MM	Craft Code	Total Labor
RF Engineer	1	1	1	EE	7635
RF Technician	1	3	3	TE	12738
Cable Installation	1	1	1	DB	9340
Total Labor					29713
Total 1.1.7.3					183270

1.1.7 RF System

1.1.7.4 RF Utilities

*** MATERIALS ***	Unit	# of Units	Unit Cost	Cost Base	Total $
LCW to Klystron	set	1	500	SP86	500
LCW to Cavity	set	1	500	SP86	500
Cables/Trays/Conduits etc	set	1	2730	SP86	2730
Contract Labor	hr	754	JL	EU	13535
Total Materials					17265

*** LABOR ***	# of Units	Units MM	Total MM	Craft Code	Total Labor
RF Technician	1	0.5	0.5	TE	2123
Total Labor					2123
Total 1.1.7.4					19388

7-16-86

TELEPHONE QUOTE FOR WAVEGUIDE
358 MHZ SYSTEM

DIRECTIONAL COUPLERS

a) REFLECTIVE	1680^{00} EA	X 2	$3,360^{00}$
b) BELLOWS	1530^{00} EA	X 4	$6,120^{00}$
c) 90° "E" PLANE BEND (SWEEP)	880^{00} EA	X 4	$3,520^{00}$
d) 90° "H" PLANE BEND (SWEEP)	1030^{00} EA	X 1	$1,030^{00}$
e) 160° H PLANE BEND	1830^{00} EA	X 2	$3,660^{00}$
f) 12' STRAIT SECTION \$480+50/FT FLANGED BOTH ENDS	1080^{00} EA.	X 3	$3,240^{00}$
g) 12' STRAIT SECTION 310+50/FT FLANGED ONE END ONLY	910^{00} EA	X 5	$4,550^{00}$
h) FLANGES	165^{00}	X 8	$1,320^{00}$
			26,800

1) ALL ABOVE MATERIAL will WITHSTAND 1/4" PSIG INTERNAL AIR PRESSURE
2) WAVEGUIDE = 3/16" WALL THICKNESS
3) MATERIAL ALUMINUM
4) ALL ITEMS PACKAGED IN PLYWOOD CRATES AT FACTORY
5) ABOVE PRICES ARE F.O.B. RAYMOND MAINE 04071
6) WAVE GUIDE HANGERS NOT PRICED
7) WAVE GUIDE SUPPORT SYSTEM NOT INCLUDED
8) ESTIMATE DOES NOT INCLUDE WINDOWS.
9) NO MECHANICAL SHOPS OR LABOR INCLUDED

TELEPHONE QUOTE FROM

WRITTEN QUOTE TO FOLLOW IN THE MAIL.

FROM
ARENG CHAN
723-0151

MICROWAVE TECHNIQUES
ATT. ED SAVOIE
(207)-655-3881
ROUTE 302
RAYMOND ME 04071

DWG. NO. 1 B of 18 SH REV.

ESTIMATE SHEET

DATE 7-8-86

1B

		CONSTRUCTION				INSTALLATION			TOTALS		
			EACH								
	WBS	ITEM	MATER K$	LABOR ~~K$~~ HRS	QTY	MAT. K$	HRS	LAB RATE	LAB. K$	MAT. K$	TOTAL M&L
1	[illegible]	SHEET 2				21.7	538	✓			
2	3071	3				0.8	18	✓			
3		4				13.0	200	✓			
4		5				28.4	516	✓			
5		6				9.8	152	✓			
6		7				7.3	128	✓			
7		8				5.9	104	✓			
8		9				10.66	327	✓			
9		10				4.48	180	✓			
10		11				7.38	310	✓			
11		12				3.10	120				
12		13				5.00	80	✓			
13		14				4.12	180	✓			
14		15				.34	65	✓			
15		16				1.25	192	✓			
16		17				14.15	140	✓			
17		SHEET - 18				1.20	753.7	✓			
18		TOTALS									

138.58 ↳ 4003.77

STANFORD X-RAY CENTER	SIZE A	FSCM NO.	DWG. NO.	REV.
DRAWN				
ISSUED	SCALE		SHEET	

DWG. NO. 11 of 18 SH REV.

KLY HV Box

ESTIMATE SHEET

DATE 7-8-86

11

	CONSTRUCTION					INSTALLATION			TOTALS		
			EACH								
	WBS	ITEM	MATER K$	LABOR ~~K$~~ HRS	QTY	MAT. K$	HRS	LAB. RATE	LAB. K$	MAT. K$	TOTAL M&L
1		DOUBLE BAY RACK	1.3	40	1	1.3	40				
2		QUADRAPLEX RECEPT/BKRS	.29	16	1	.29	16				
3		MONITOR (HV)	.30	32	1	.30	32				
4		SPARK GAP	.19	32	1	.19	32				
5		SPARK GAP DRIVER	1.2	40	1	1.2	40				
6		CROWBAR	.4	32	1	.4	32				
7		EARTH QUAKING MTG	.10	16	1	.10	16				
8											
9		ANALOG VOLTAGE CABLE	.05	8	1	.05	8				
10		ANALOG CURRENT CABLE	.05	8	1	.05	8				
11		DC CONTROLS CABLE	.05	8	1	.05	8				
12		AC CONTROLS CABLE	.05	8	1	.05	8				
13											
14		MISC CONNECTORS &	1.25	30	1	1.25	30				
15		FABBED PIECES	2.25	40	1	2.25	40				
16											
17											
18											
						7.38 ✓	310				

STANFORD X-RAY CENTER

DRAWN	SIZE A	FSCM NO.	DWG. NO.	REV.
ISSUED	SCALE		SHEET	

DWG. NO. 13 of 15 | SH | REV.

AC CONTACTOR

ESTIMATE SHEET

DATE 7-8-86

13

	CONSTRUCTION					INSTALLATION			TOTALS		
			EACH								
	WBS	ITEM	MATER K$	LABOR HR	QTY	MAT. K$	HRS	LAB. RATE	LAB. K$	MAT. K$	TOTAL M&L
1		UNKNOWN AT PRESENT									
2		ESTIMATE	5,0	80	1	5,0	80	1			
3											
4											
5											
6											
7											
8											
9											
10											
11											
12											
13											
14											
15											
16											
17											
18											
						5,0	80				

STANFORD X-RAY CENTER

DRAWN	SIZE A	FSCM NO.	DWG. NO.	REV.
ISSUED	SCALE		SHEET

DWG. NO. 12 of 18 | SH | REV.

Kly HV Power Supply

ESTIMATE SHEET

DATE 7-8-86

12

		CONSTRUCTION				INSTALLATION			TOTALS		
			EACH								
	WBS	ITEM	MATER K$	LABOR Hrs	QTY	MAT. K$	HRS	LAB. RATE	LAB. K$	MAT. K$	TOTAL M&L
1		Power Supply Installation	.4	40	1	.4	40				
2		Earthquaking	.2	16	1	.2	16				
3		Junction Box HV,	.2	16	1	.2	16				
4		Junction Control Cable	.05	8	1	.05	8				
5		Control Cable	.05	8	1	.05	8				
6		LINKS TO UVT ? etc	2.2	32	1	2.2	32				
7											
8											
9											
10											
11											
12											
13											
14											
15											
16											
17											
18											

3.1 120

STANFORD X-RAY CENTER

DRAWN	SIZE A	FSCM NO.	DWG. NO.	REV
ISSUED	SCALE		SHEET	

DWG. NO. 2 of 18 SH REV.

BAY 1

ESTIMATE SHEET

02

DATE 7-1-86

		CONSTRUCTION				INSTALLATION			TOTALS		
			EACH								
	WBS	ITEM	MATER K$	LABOR ~~K$~~ HRS	QTY	MAT. K$	HRS	LAB. RATE	LAB. K$	MAT. K$	TOTAL M&L
1		LOW LEVEL PWR 206-414	0.05	8	1	.05	8				
2		PATCH PNL 'N'	.35	8	1	.35	8				
3		PATCH PNL 'BNC'	.35	8	1	.35	8				
4		TUNER DRIVER 206-402	.60	24	3	1.8	72				
5		CAV PHASE DET 206-403	1.0	24	1	1.0	24				
6		CAV SERVO AMP 206-412	1.0	24	1	1.0	24				
7		ARC DETECTOR 206-448	.75	24	1	.75	24				
8		GAP VOLTAGE COM 206-407	1.0	18	1	1.0	18				
9		REFL. PWR DET 206-425	1.5	32	1	1.5	32				
10		LOCAL OSCILLATOR 206-408	.8	32	1	.8	32				
11		R.F. ATTEN 206-413	2.0	36	1	2.0	36				
12		NULLING PHASE SH 206-422	1.5	24	1	1.5	24				
13		FAST R.F. DUMP 206-452	1.5	24	1	1.5	24				
14		KLYSTRON PHASE SH 206-429	1.5	18	1	1.5	18				
15		PHASE LOCK AMP 206-416	.9	24	1	.9	24				
16		KLYSTRON PHASE DET 206-403	1.2	24	1	1.2	24				
17		LOC. OSC FANOUT 206-420	.6	18	1	.6	18				
18		DOUBLE BAY RACK BUILD	1.3	40	3	3.9	120				
						21.7	538				

STANFORD X-RAY CENTER	SIZE A	FSCM NO.	DWG. NO.	REV.
DRAWN				
ISSUED	SCALE		SHEET	

DWG. NO. 3 of 18 | SH | REV.

BAY 1

ESTIMATE SHEET

03

DATE 7-1-86

		CONSTRUCTION				INSTALLATION			TOTALS		
			EACH								
	WBS	ITEM	MATER K$	LABOR ~~K$~~ HRS	QTY	MAT. K$	HRS	LAB. RATE	LAB. K$	MAT. K$	TOTAL M&L
1		BLOWER	.150	2	2	.3	2				
2		CROSSCONNECTS	.5	16	1 Assy	.5	16				
3											
4											
5											
6											
7											
8											
9											
10											
11											
12											
13											
14											
15											
16											
17											
18											

.8 ✓ 18

STANFORD X-RAY CENTER

DRAWN	SIZE A	FSCM NO.	DWG. NO.	REV.
ISSUED	SCALE		SHEET	

DWG. NO. 5 of 18 | SH | REV.

BAY -3

ESTIMATE SHEET

DATE 7-7-86

05

		CONSTRUCTION				INSTALLATION			TOTALS		
			EACH								
	WBS	ITEM	MATER K$	LABOR ~~K$~~ HRS	QTY	MAT. K$	HRS	LAB. RATE	LAB. K$	MAT. K$	TOTAL M&L
1		SPLIT BUS TIE 206-314	.040	8	1	0.04	8				
2		DC CIRCUIT BREAKERS	.060	4	1	0.06	4				
3		INDICATOR PANEL 206-300	.25	36	4	1.00	144				
4		RF STATION Controller 206-301	2.25	120	1	2.25	120				
5		CAMAC CRATE	5.00	8	1	5.1	8				
6		LOCAL & REMOTE Swt 206-302	.250	32	1	.25	32				
7		CROSS CONNECTS	.5	16	1ASSY	.5	16				
8		CRATE VERIFIER 123-589	3.0	8	1	3.0	24				
9		ANALOG MON (SAM) 123-603	2.1	24	2	4.2	24				
10		ANALOG Control 208-605	2.0	24	1	2.0	24				
11		DIGITAL Control 135-568	1.0	24	1	1.0	24				
12		DIGITAL MONITOR 206-609	1.0	24	4	4.0	96				
13	?	BRANCH Receiver 135-337	2.5	8	1	2.5	8				
14		CRATE Controller 135-279	2.5	8	1	2.5	8				
15											
16											
17											
18											
						28.4	516				

STANFORD X-RAY CENTER

DRAWN	SIZE A	FSCM NO.	DWG. NO.	REV.
ISSUED	SCALE		SHEET	

DWG. NO. 6 of 18 SH REV.

BAY 4

ESTIMATE SHEET

DATE 7/8/86

06

		CONSTRUCTION				INSTALLATION			TOTALS		
			EACH								
	WBS	ITEM	MATER K$	LABOR HRS	QTY	MAT K$	HRS	LAB RATE	LAB K$	MAT K$	TOTAL M&L
1		THERMOCOUPLE MONITOR	2.4	40	1	2.4	40				
2		RF POWER METER	4.0	8	1	4.0	8				
3		RF POWER METER INPUT	1.5	24	1	1.5	24				
4		KLYSTRON AUX HV Controller 206-602	.9	48	1	.9	48				
5		CROSS CONNECTS	.5	32	2 Assy	1.0	32				
6		24V Power Supply (SOLA)									
7											
8											
9											
10											
11											
12											
13											
14											
15											
16											
17											
18											

9.8 / 152

STANFORD X-RAY CENTER

DRAWN	SIZE A	FSCM NO.	DWG. NO.	REV.
ISSUED	SCALE		SHEET

DWG. NO. 16 of 18 SH REV.

CABLES To I&C

ESTIMATE SHEET

DATE 7-8-86

16

	CONSTRUCTION					INSTALLATION			TOTALS		
			EACH								
	WBS	ITEM	MATER K$	LABOR ~~K$~~ HRS	QTY	MAT. K$	HRS	LAB. RATE	LAB. K$	MAT. K$	TOTAL M&L
1		PATCH RG-214	.06	8	8	.48	64				
2		PATCH RG-58/u	.05	8	8	.40	64				
3		RF STATION 12C16	.05	8	1	.05	8				
4		KLY AUX CONT 12C16	.05	8	1	.05	8				
5		LOCAL OSC FANOUT RG142	.08	8	1	.08	8				
6		PPI 8C16	.05	8	1	.05	8				
7		PCR TRANSFER PNL 12C16	.05	8	1	.05	8				
8		POWER (24V) #2 AWG	.02	8	2	.04	16				
9		VACUUM INTERLOCK 8C16	.05	8	1	.05	8				
10											
11											
12											
13											
14											
15											
16											
17											
18											

1.25 / 192

STANFORD X-RAY CENTER

DRAWN

ISSUED

SIZE A

FSCM NO.

DWG. NO.

REV.

SCALE

SHEET

DWG. NO. 7.R18 SH REV.

BAY 5

ESTIMATE SHEET

DATE 7/8/06

07

	CONSTRUCTION					INSTALLATION			TOTALS		
			EACH								
	WBS	ITEM	MATER K$	LABOR ~~K$~~ HRS	QTY	MAT. K$	HRS	LAB. RATE	LAB. K$	MAT. K$	TOTAL M&L
1		RELAY MODULES	1.6	16	3MOD	4.8	48				
2		CROSS CONNECTS	.5	16	5MOD	2.5	80				
3											
4											
5											
6											
7											
8											
9											
10											
11											
12											
13											
14											
15											
16											
17											
18											

7.3✓ 128

STANFORD X-RAY CENTER

DRAWN	SIZE A	FSCM NO.	DWG. NO.	REV.
ISSUED	SCALE		SHEET

DWG. NO. 4 OF 15 SH REV.

BAY 2

ESTIMATE SHEET

DATE 7-1-86

04

	CONSTRUCTION					INSTALLATION			TOTALS		
			EACH								
	WBS	ITEM	MATER K$	LABOR ~~K$~~ HRS	QTY	MAT. K$	HRS	LAB. RATE	LAB. K$	MAT. K$	TOTAL M&L
1		TUNER DRIVER MOTOR P/S	3.0	8	1	3.0	8				
2		LOW LEVEL PWR SUP	3.3	16	1	3.3	16				
3		RF DISPLAY PANEL 206-301	1.4	36	1	1.4	36				
4		ANALOG DIST (IN) 208-607	.8	32	3	2.4	32				
5		ANALOG DIST (OUT) 208-608	.8	32	1	.8	32				
6		RF AMPLITUDE DET 206-426	1.6	60	1	1.6	60				
7		CROSS CONNECT	.5	16	1 ASSY	.5	16				
8											
9											
10											
11											
12											
13											
14											
15											
16											
17											
18											

13.0 // 200

STANFORD X-RAY CENTER

DRAWN	SIZE A	FSCM NO.	DWG. NO.	REV.
ISSUED	SCALE		SHEET	

DWG. NO. 18 of 18 SH REV.

UTILITIES / MISC

ESTIMATE SHEET

DATE 7-8-86

18

CONSTRUCTION

			EACH		TOTAL	INSTALLATION			TOTALS		
	WBS	ITEM	MATER K$	LABOR ~~K$~~ HRS	QTY	MAT. K$	HRS	LAB. RATE	LAB. K$	MAT. K$	TOTAL M&L
1		RG 220 CABLE To HV Box 20'	.06	8	1	.06	8				
2		CABLE TRAYS	.5	40	1	.5	40				
3		CONDUIT	.25	20	1	.25	20				
4		LCW WATER To KLYSTRON	.50	40	1	.50	40				
5		LCW To CAVITY	.50	40	1	.50	40				
6	(	CrossConnect Jumpers	.12	174	1	.12	174	(x			
7		CABLES (Chassis to Crossconnects)	.6	348	1	.6	348	x			
8		EXTERNAL CABLES	1.2	80	1	1.2	80				
9											
10											
11											
12											
13											
14											
15											
16											
17											
18											
						3.73	753.73				

STANFORD X-RAY CENTER

DRAWN	SIZE A	FSCM NO.	DWG. NO.	REV.
ISSUED	SCALE		SHEET	

DWG. NO. 9 of 18 SH REV.

CAVITY

ESTIMATE SHEET

DATE 7/8/86

09

		CONSTRUCTION				INSTALLATION			TOTALS		
			EACH								
	WBS	ITEM	MATER K$	LABOR ~~K$~~ HRS	QTY	MAT. K$	HRS	LAB. RATE	LAB. K$	MAT. K$	TOTAL M&L
1		CAV Junction Box	.12	36	1	.12	36				
2		TUNER DRIVER ASSY	3.15	80	2	6.3	160				
3		TUNER DRIV ASSY (FREQ CHANG)	3.15	80	1	3.15	80				
4		THERMOCOUPLE CABLES	.06	2	6	.36	12				
5		Coax (Cell sense)	.06	3	5	.30	15				
6		CAV FWD PWR COAX	.06	3	1	.06	3				
7		CAV REF PWR COAX	.06	3	1	.06	3				
8		CAV LIMIT SWITCHES CABLE	.05	3	1	.05	3				
9		CAV MOTOR WINDINGS CABLE	.05	3	1	.05	3				
10		CAV FLOW SWITCHES CABLE	.05	3	1	.05	3				
11		CAV CELL 1-5 POSITION INDICATION CABLE	.06	3	2	.10	6				
12		CAV ARC DETECTOR CABLE	.06	3	1	.06	3				
13		CAVITY TUNER DRIVER									
14		WAVEGUIDE									
15											
16											
17											
18											

10.66 ✓ 327

STANFORD X-RAY CENTER

DRAWN

ISSUED

SIZE A

FSCM NO.

DWG. NO.

REV.

SCALE

SHEET

DWG. NO. 8 of 18 SH REV.

BAY 6

ESTIMATE SHEET

DATE 7-3-86

08

		CONSTRUCTION				INSTALLATION			TOTALS		
			EACH								
	WBS	ITEM	MATER K$	LABOR ~~K$~~ HRS	QTY	MAT. K$	HRS	LAB. RATE	LAB. K$	MAT. K$	TOTAL M&L
1		3φ BUS TIE	.15	8	1	.15	8				
2		AC POWER Disconnect	.20	8	1	.20	8				
3		AC BUS PNL DIST	.35	8	1	.35	8				
4		AC CIRCUIT BREAKER	.35	8	1	.35	8				
5		KLY FOCUS MONITOR	1.2	32	1	1.2	32				
6		KLY FOCUS P/S 1	1.4	8	1	1.4	8				
7		KLY FOCUS P/S 2	1.5	8	1	1.5	8				
8		GROUND BUS	.25	8	1	.25	8				
9		AC CROSS Connect	.5	16	1	.5	16				
10											
11											
12											
13											
14											
15											
16											
17											
18											

5.9 ✓ 104 ✓

STANFORD X-RAY CENTER

DRAWN	SIZE A	FSCM NO.	DWG. NO.	REV.
ISSUED	SCALE		SHEET	

DWG. NO. 10 of 18 SH REV.

KLYSTRON

ESTIMATE SHEET

DATE 7-8-86

10

CONSTRUCTION

	WBS	ITEM	EACH MATER K$	EACH LABOR ~~K$~~ HRS	QTY	INSTALLATION MAT. K$	INSTALLATION HRS	INSTALLATION LAB. RATE	TOTALS LAB. K$	TOTALS MAT. K$	TOTALS TOTAL M&L
1		KLYSTRON MONITOR PANEL	.3	24	1	.3	24				
2		RG220	.3	16	1	.3	16				
3		KLY HEATER 3C/16	.02	8	1	.02	8				
4		SWITCH CONTROL 8C-16	.05	8	1	.05	8				
5		HP POWER METER CABLE	.4	8	1	.4	8				
6		AC POWER 3-16 TUREX	.02	8	1	.02	8				
7		RF DRIVE INPUT RG214	.6	8	1	.6	8				
8		KLY AMP PWR 3-16	.02	8	1	.02	8				
9		(FROM 20Db Cplg RG-214	.6	8	1	.6	8				
10		ARC DET. 3C-16	.02	8	1	.02	8				
11		REFLECTED PWR TO PATCH RG214	.6	8	1	.6	8				
12		TO REFLECTED PWR DET RG214	.6	8	1	.6	8				
13		VAC INTERLOCK 8C-16	.05	12	1	.05	12				
14		KLYSTRON PRESS SWITCH 8C-16	.05	12	1	.05	12				
15		RF DRIVE TO PATCH RG214	.6	8	1	.6	8				
16		WAVEGUIDE PRESS SW. 8C-16	.05	12	1	.05	12				
17		VARIAN CABLE	.22	16	1	.22	16				
18											
						4.48✓	180				

STANFORD X-RAY CENTER

DRAWN	SIZE A	FSCM NO.	DWG. NO.	REV.
ISSUED	SCALE		SHEET	

14 of 18

KLYSTR WATER RACK ESTIMATE SHEET DATE 7-8 86

14

		CONSTRUCTION				INSTALLATION			TOTALS		
			EACH								
	WBS	ITEM	MATER K$	LABOR HRS	QTY	KS	HRS	LAB. RATE	LAB. K$	MAT. K$	TOTAL M&L
1		FRAME	1.3	40	1	1.3	40				
2		Hoses To KLYSTRON	.3	10	4	1.2	40				
3		GAGES "	.12	8	4	.48	32				
4		Flow Switches	.2	6	4	.8	24				
5		MECHANICAL BRIDGING	.3	36	1	.3	36				
6		CABLE 26C22	.04	8	1	.04	8				
7		PLUMBING Tubes etc									
8											
9											
10											
11											
12											
13											
14											
15											
16											
17											
18											

4.12 ✓ 180

STANFORD X-RAY CENTER	SIZE A	FSCM NO.	DWG. NO.	REV.
DRAWN				
ISSUED	SCALE		SHEET	

DWG. NO. 15 of 18 SH REV.

KLYSTRON ΔT JUNCT BOX

ESTIMATE SHEET

DATE 7-5-86

15

		CONSTRUCTION				INSTALLATION			TOTALS		
			EACH								
	WBS	ITEM	MATER K$	LABOR ~~K$~~ HRS	QTY	MAT. K$	HRS	LAB. RATE	LAB. K$	MAT. K$	TOTAL M&L
1		JUNCTION BOX	.15	32	1	.15	32				
2		SENSORS	.03	5	5	.150	25				
3		CABLE	.04	8	1	.04	8				
4											
5											
6											
7											
8											
9											
10											
11											
12											
13											
14											
15											
16											
17											
18											

.34 ✓ 65

STANFORD X-RAY CENTER	SIZE A	FSCM NO.	DWG. NO.	REV.
DRAWN				
ISSUED	SCALE		SHEET	

DWG. NO. 17 of 18 SH REV.

KLYSTRON MONITOR PANEL

ESTIMATE SHEET

DATE 7-8-86

17

CONSTRUCTION

	WBS	ITEM	EACH MATER K$	EACH LABOR ~~K$~~ HRS	QTY	INSTALLATION MAT. K$	INSTALLATION HRS	INSTALLATION LAB. RATE	TOTALS LAB. K$	TOTALS MAT. K$	TOTAL M&L
1		PANEL	.050	4	1	.2	4				
2	*	COUPLERS	.80	4	5	4.0	20				
3	*	PADS	.60	4	2	2.4	8				
4	*	ISOLATOR	1.5	8	1	1.5	8				
5	*	Amplifier	2.0	32	1	2.0	32				
6	*	50 Ω TERMINATOR	.4	8	1	.4	8				
7	*	SWITCH (RF Type)	.35	16	1	.35	16				
8		PRESSURE SWITCHES	.15	12	2	.30	24				
9	*	Connectors (MISC) ELBOWS etc	.3	2	10	3.0	20				
10											
11											
12											
13											
14											
15											
16											
17											
18											

14.15 140

* GUESS IN PRICE

STANFORD X-RAY CENTER

DRAWN

ISSUED

SIZE A

FSCM NO.

DWG. NO.

REV.

SCALE

SHEET

1.1.8 I & C SYSTEM

1.1.8.0 E D & I

*** LABOR ***	# of Units	Units MM	Total MM	Craft Code	Total Labor
Electr. Engineering	1	21	21	EE	160345
Coordinator	1	18	18	CS	94568
Electrical Designer	1	18	18	ED	98771
Documentation Clerk	1	9	9	DC	24703
Total Labor					378386
Total 1.1.8.0					378386

1.1.8 I & C SYSTEM

1.1.8.1 Beam Diagnostics

1.1.8.1.1 Beam Position Monitoring

*** MATERIALS ***	Unit	# of Units	Unit Cost	Cost Base	Total $
Cabling	800 ft	28	600	SP86	16800
Interface Chassis	each	1	4000	SP86	4000
Processor Module	each	1	2000	SP86	2000
Control Cables	each	1	1200	SP86	1200
SAM	each	1	2000	SP86	2000
Attenuator Module	each	1	4000	SP86	4000
RIOT MUX	each	10	1250	SP86	12500
Contract Labor	hr	478	JL	SP86	8581
misc.Mat./Fittings etc.	each	28	200	EU	5600
Installation	hr	296	JL	SP86	5314
Scopes,Meters etc.	lot	1	30000	CP	30000
Total Materials					91994

*** LABOR ***	# of Units	Units MM	Total MM	Craft Code	Total Labor
	1.00	2	2	EE	15271
	1.00	4	4	TE	16984
Total Labor					32254

Total 1.1.8.1.1	124249

1.1.8 I & C SYSTEM

1.1.8.1 Beam Diagnostics

1.1.8.1.2 Intensity Monitoring (Electronics)

*** MATERIALS ***	Unit	# of Units	Unit Cost	Cost Base	Total $
Synchr.Light TV/Camera	each	1	5200	SP86	5200
Gap Monitor	each	4	1200	SP86	4800
Profile Monitor	each	1	6300	SP86	6300
Faraday Cup	each	1	2200	SP86	2200
Tune Monitor	each	1	15200	SP86	15200
Scrapers	each	2	1600	SP86	3200
Assembly/Installation	hr	840	JL	SP86	15079
misc. materials	lot	1	1500	EU	1500
Cabling	lot	1	5000	EU	5000
Instrumentation	set	1	9000	CD	9000
Total Materials					67479

*** LABOR ***	# of Units	Units MM	Total MM	Craft Code	Total Labor
	1	4	4	EE	30542
Installation	1	1	1	DB	9340
Total Labor					39882
Total 1.1.8.1.2					107361

1.1.8 I & C SYSTEM

1.1.8.1 Beam Diagnostics

1.1.8.1.3 Timing System

*** MATERIALS ***	Unit	# of Units	Unit Cost	Cost Base	Total $
Master Oscillator	each	1	12100	SP86	12100
Set of Prog. Delay Units	set	1	16000	SP86	16000
Inj./Ejec. Timing	each	1	4000	EU	4000
Contract Labor	hr	530	JL	EU	9514
Instrumentation	lot	1	25000	CP	25000
Total Materials					66614

*** LABOR ***	# of Units	Units MM	Total MM	Craft Code	Total Labor
	1	2	2	EE	15271
	1	2	2	TE	8492
Total Labor					23763

Total 1.1.8.1.3	90377

1.1.8 I & C SYSTEM

1.1.8.2 Control System

1.1.8.2.1 Interface/Controllers

*** MATERIALS ***	Unit	# of Units	Unit Cost	Cost Base	Total
Large Supply Controller	each	1	4200	SP86	4200
Operator-Comp Int.	each	1	2000	SP86	2000
Control Cabling	set	1	4200	SP86	4200
Pulsed Magnet Controls	each	4	2100	SP86	8400
Prog Controllers	set	1	9000	SP86	9000
Cross Connects	each	1	1000	SP86	1000
DACS	each	20	1500	A86	30000
SAMS	each	10	1500	A86	15000
Fanout Chassis	each	2	2000	A86	4000
Fanin Chassis	each	2	2000	A86	4000
Assembly/Installation	hr	450	JL	SP86	8078
Total Materials					89878

*** LABOR ***	# of Units	Units MM	Total MM	Craft Code	Total Labor
	1	2	2	EE	15271
	1	6	6	TE	25475
Total Labor					40746

Total 1.1.8.2.1	130624

1.1.8 I & C SYSTEM

1.1.8.2 Control System

1.1.8.2.2 Software

*** MATERIALS ***	Unit	# of Units	Unit Cost	Cost Base	Total $
System Prog.	lot	1	1000	EU	1000
Application Prog.	lot	1	1000	EU	1000
Total Materials					2000

*** LABOR ***	# of Units	Units MM	Total MM	Craft Code	Total Labor
System Prog.	1	6	6	PR	38342
Application Prog.	1	12	12	PR	76683
Total Labor					115025

Total 1.1.8.2.2	117025

1.1.8. I & C SYSTEM

1.1.8.2 Control System

1.1.8.2.3 Racks/Cables/Tr

*** MATERIALS ***	Unit	# of Units	Unit Cost	Cost Base	Total $
Racks	each	13	2000	A86	26000
Trays	100 ft	18	550	SP86	9900
Tray EL's	each	48	50	SP86	2400
Misc. Materials	lot	1	2000	SP86	2000
Total Materials					40300

*** LABOR ***	# of Units	Units MM	Total MM	Craft Code	Total Labor
	2	1	2	DB	18680
Total Labor					18680
Total 1.1.8.2.3					58980

1.1.8 I & C SYSTEM

1.1.8.2 Control System

1.1.8.2.4 Computer Controls

*** MATERIALS ***	Unit	# of Units	Unit Cost	Cost Base	Total $
Terminals	each	2	1500	CP	3000
Camac Interface	each	1	9000	SP86	9000
Camac Crates	each	4	2275	SP86	9100
Crate Controller	each	4	2900	SP86	11600
Crate Verifier	each	4	1000	SP86	4000
Operator Console	each	1	40000	SP86	40000
Contract Labor	hr	1040	JL	EU	18669
Misc. Materials	lot	1	2500	EU	2500
Total Materials					97869

*** LABOR ***	# of Units	Units MM	Total MM	Craft Code	Total Labor
	1.00	2	2	EE	15271
	1.00	4	4	TE	16984
Total Labor					32254

Total 1.1.8.2.4	130124

1.1.8 I & C System

1.1.8.3 Protection System

*** MATERIALS ***	Unit	# of Units	Unit Cost	Cost Base	Total $
Entry Stations	each	2	7500	SP86	15000
Main Control Panel	each	1	3000	SP86	3000
Emergencies Off	each	5	1500	SP86	7500
Cable Plant	ft	2000	3	SP86	6000
Misc. Material	lot	1	1000	SP86	1000
Contract Labor	hr	173	JL	EU	3111
Total Materials					35611

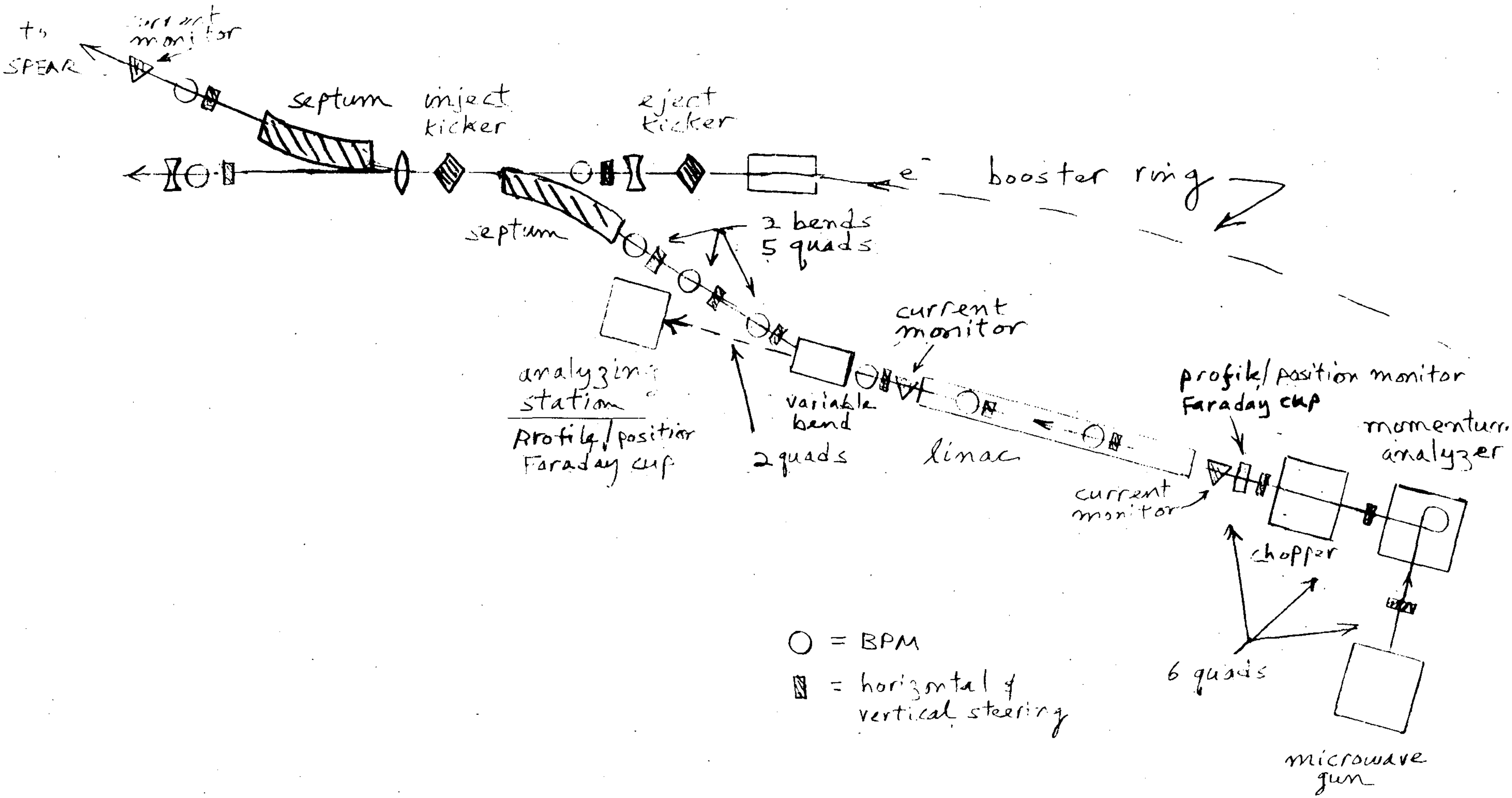
*** LABOR ***	# of Units	Units MM	Total MM	Craft Code	Total Labor
Installation	2	1.50	3	DB	28020
Total Labor					28020
Total 1.1.8.3					63631

1.1.8 I & C System

1.1.8.4 Communication

*** MATERIALS ***	Unit	# of Units	Unit Cost	Cost Base	Total $
Paging/Intercom	each	1	2500	EU	2500
Telephone	each	1	5000	EU	5000
Total Materials					7500

*** LABOR ***	# of Units	Units MM	Total MM	Craft Code	Total Labor
Installation	1	0.50	1	DB	4670
Total Labor					4670
Total 1.1.8.4					12170


to SPEAR
current monitor
septum
inject kicker
eject kicker
e⁻
booster ring
septum
3 bends
5 quads
current monitor
analyzing station
Profile/position Faraday cup
variable bend
2 quads
linac
profile/position monitor
Faraday cup
momentum analyzer
current monitor
chopper
6 quads
microwave gun
○ = BPM
▨ = horizontal & vertical steering

SUBSYSTEM	QUANT	MATL K$	INT. HRS	TEST K$	INST. MAT. K$	INST. HRS	LABOR K$	TOTAL K$	REMARK
1. LARGE SUPPLY									DOES NOT INCLUDE SUPPLY
CONTROLLER	1	2	40	.7	.5	5	.1	3.3	
PSC	1	1.5	—	—	.2	5	.1	1.8	
2. QUAD & SEXT. SUPPLIES	104	176.8	—	—	—	150	2.4	179.2	
SAMS	4	8	—	—	—	—	—	8	
DACS	8	12	—	—	—	—	—	12	
(95 QUADS) (42 SEXTS) 137 POWER BUSSING #4 WIRE	44,000'	11	—	—	1	385	6.6	18.6	
RACKS	5	10	200	3.3	—	50	1.0	14.3	
CONTROL CABLING	1 set	3	80	1.4	.1	80	1.4	5.9	
FANOUT CHASSIS	4	4	—	—	—	—	—	4	
3. TRIM SUPPLIES (5x16)	70	37.3	—	—	—	24	.5	37.8	
SAMS	3	6	—	—	—	—	—	6	
DACS	6	9	—	—	—	—	—	9	
POWER BUSSING #14	29,000'	1.5	—	—	1	240	4.8	7.3	
RACKS	2	4	40	.8	—	16	.3	5.1	
CONTROL CABLING	1 set	2	40	.7	.1	40	.8	3.6	
BULK SUPPLIES	6	12	—	—	—	10	.2	12.2	
4. PULSED CONTROLS	4	8	100	1.7	1	100	1.7	12.4	- DOES NOT INCLUDE SUPPLIES
5. INJECTION LINE DC SUPPLIES									
2 CONT. VUV BYPASS SWITCHES (5x8)	40	4.0	80	1.4	0.5	16	0.3	6.2	
TOTALS		312.1	580	10.0	4.4	1121	20.2	346.7	

SUBSYSTEM	QUANT	MATL K$	INT. & TEST HRS	INT. & TEST K$	INST. MAT. K$	INST. HRS	LABOR K$	TOT. K$	REMARK
1. POSITION MONITORS	50								
CABLING	38,000	29.1	260	4.6	-	260	4.6	38.3	
INTERFACE CHASSIS	1	4	40	.7	-	10	.2	4.9	
RIOT MUX	20	25	250	4.4	-	25	0.5	29.9	
ATTEN MOD.	2	4	40	.7	—	—	—	4.7	
PROCESSOR MODULE	1	2	100	1.7	—	100	1.7	5.4	
SAM	1	2	—	—	—	—	—	2	
CONTROL CABLES	1	1	40	.7	.2	20	.4	2.3	
2. DCCT	1	2	160	2.8	.2	20	.4	5.4	
3. SYNC LIGHT MON	1	5	200	3.5	.2	20	.4	9.1	
4. SCRAPERS	2 (X,Y)	3	120	2.0	.2	20	.4	5.6	
5. TUNE MONITOR	1	15	120	2.0	.2	20	.4	17.6	
FARADAY CUP	1	2	40	.7	.2	20	.4	3.3	
GAP MONITOR	1	1	20	.4	.2	20	.4	2.0	
PROFILE MONITOR	2	6	80	1.4	.3	40	.8	8.5	
6. MISC CONSOLE EQUIP SCOPES, ETC	1	20	—	-	—	—	—	20	
TOTALS		121.1	1470	25.6	1.7	575	10.6	159.0	

1.1.2.1.2

SUBSYSTEM	QUANT	MATL K$	INT. HRS	TEST K$	INST. MAT. K$	INST. HRS	LABOR K$	TOTAL K$	REMARK
1. MASTER OSCILLATOR	1	12	–	—	.1	10	.2	12.3	
2. PROG. DEL. UNITS	?	15	300	5.1	1	100	1.7	22.8	
3. INJ TIMING	1	3	80	1.4	1	40	.7	6.1	
TOTALS		30	380	6.5	2.1	150	2.6	41.2	

SUBSYSTEM	QUANT	MATL K$	INT. TEST		INST. MAT. K$	INST. LABOR		TOTL K$	REMARX
			HRS	K$		HRS	K$		
1. PROG CONTROLLER	1	8	—	—	2	100	1.7	11.8	
2. CROSS CONNECTS	1	2	–	—	.2	60	1	3.2	
3. OPERATOR & COMPUTER INT. 1 IDIm, 1 IDom, PANEL	1	4	20	.4	.1	20	.4	4.9	
TOTALS		14	20	.4	2.3	180	3.1	19.8	

SUBSYSTEM	QUANT	MATL K$	INT. & TEST HRS	INT. & TEST K$	INST. MAT. K$	INST. LABOR HRS	INST. LABOR K$	TOTL K$	REMARK
1. GUAGE CONT/Cable	18	27.0	270	4.7	6	72	1.3	39.0	
BAKABLE ~~LONG~~ CABLES	18	5.4	—	—	—	—	—	5.4	
2. PUMP SUPPLIES	8	16.0	—	—	—	16	.3	16.3	
BAKABLE CABLE	80	24.0	—	—	—	48	1.0	25.0	
CABLE DIST SYSTEM (JUNCTION BOXES & HV CABLE)	80 (BOXES)	1.1	—	—	1.1 (CABLE)	240	4.8	7.0	2300'
3. IV ~~VALVES~~ CONT.	6	3.0	30	0.6	0.8	30	0.6	5.0	VAT VALVES
4. FAST VALVE CONT	—								T
5. FAST SENSORS	—								S
6.									
TOTALS		76.5	300	5.3	7.9	406	8.0	97.7	

SUBSYSTEM	QUANT	MAT L K$	INT. & TEST HRS	INT. & TEST K$	INST. MAT. K$	INST. LABOR HRS	INST. LABOR K$	TOT K$	REMARK
1. ENTRY STATIONS	2	20K	200	3.4	2	200	3.4	28.8	
2. MAIN CONTROL PANEL	1	3K	80	1.4	1	40	.7	6.1	
3. EMER. OFF BUTTONS	10	3K	40	.7	.1	40	.7	4.5	
4. CABLE PLANT	1000'	~~3K~~ —	—	—	3	200	3.4	6.4	
5. MISC INT.	1	1K	80	1.4	1	100.	1.7	5.1	
TOTALS		27	400	6.9	7.1	580	9.9	50.9	

SUBSYSTEM	QUANT	MATL K$	INT. HRS	B! TEST K$	INST. MAT. K$	INST. HRS	LABOR K$	TOT. K$	REMARKS
1. RACKS (DOUBLES) ~~CONSOLE 4~~ NO PWR SUP ~~VAC 3~~ NO RF ~~B[illegible] 2~~	18	36	720	11.7	—	170	3.4	51.1	
2. TRAYS									
RING - 350' X 2 - 8" TO RACKS - 120' - 12"	850' - 8" 230' - 12"	6.	—	—		150	3	15.6	
TO CR - 80' - 12"	500' - 4" DB	2.8	—	—		100	2		
4" ///U DUCT BANK - 350' + 75'	20 EL'S + T'S	1	—	—		40	.8		
TO TRUNK 30' - 12"									
INJECTION #75 X 2 - 8"									
INJ 4" DUCT 75 - 4"									
3.									
TOTALS		45.8	720	11.7	-	460	9.2	66.7	

STANFORD SYNCHROTRON RADIATION LABORATORY **ENGINEERING NOTE**	CODE	SERIAL	PAGE OF
AUTHOR R. Hettel, P. Wang	DEPARTMENT Injector	LOCATION	DATE 8-10-87

RF & I&C Instrumentation

1.1.4.7 Linac Beam Diagnostics

a. HP816A + HP809C + HP447B (slotted line + carriage + probe)	2.5K
b. Misc. →	2.5K
	Total: 5K

1.1.7.3 RF Drive System/Controls

a. HP 8656B Signal Generator + options	7k
b. HP 8405A Vector Voltmeter + options	6.7k
c. HP 435B Power Meter + Sensors	2.3k
d. Coaxial Components	3k
e. HP8620C + HP86235A Sweep Oscillator + options	12k
f. HP 5350A + options Frequency Counter	6.5k
g. Misc.	2.5K
	Total = 40k

1.1.8.1.1 Beam Position Monitoring

a. Tektronix 2467 Scope + probes + cart	13K
b. Tektronix C-30B opt 01 Scope Camera	1.5K
c. SLAC Fast Pulser	1.2K
d. HP8495A 70dB Attenuator	.5k
e. HP8494A 11 dB Attenuator	.7k
f.	
	Total = 16.9k

1.1.8.1.2 Intensity Monitoring

a. Tektronix 7L14 + R7603 Spectrum Analyzer	21.5k
b. HP3314A Function Generator opt 001	4.5k
c. HP3457A DMM + accessories	3k
d. Misc tools + cables	1.5K
	Total = 30.5K

1.1.8.1.3 Timing System

a. HP8082A Pulse Generator + accessories	5.1k
b. HP5386A opt 004 Frequency Counter	3.4k
c. Tektronix 2465 Scope + options	6k
d. Power Supplies: HP6236B + HP6237B + HP6205C	2.1k
	Total = 16.6k

7600-54250

RL-3220 (Rev. 5/75)

1.1.9 INJECTION/EJECTION

1.1.9.0 E D & I

*** LABOR ***	# of Units	Units MM	Total MM	Craft Code	Total Labor
Electr. Engineering	1	6	6	EE	45813
Mech. Engineering	1	12	12	ME	92638
Mechanical Designer	1	12	12	MD	65847
Electrical Designer	1	6	6	ED	32924
Total Labor					237221
Total 1.1.9.0					237221

1.1.9 INJECTION/EJECTION

1.1.9.1 Transport Lines

1.1.9.1.1 Linac-Booster 150 MeV

*** MATERIALS ***	Unit	# of Units	Unit Cost	Cost Base	Total $
Bend Magnets	each	2	750	EU	1500
Quadrupoles	each	5	500	EU	2500
Steering Magnets	each	6	250	EU	1500
Support	set	1	2000	EU	2000
Power Supplies	each	7	1600	A86	11200
small Power Supplies	each	6	800	A86	4800
Cabling	lot	1	2500	EU	2500
misc. Materials	lot	1	1800	EU	1800
Contract Labor	hr	480	JL	EU	8617
Total Materials					36417

*** LABOR ***	# of Units	Units hr	Total MM	Craft Code	Total Labor
	1	40	0.23	ME	1785
	1	240	1.39	TM	9005
Total Labor					10790
Total 1.1.9.1.1					47207

1.1.9 INJECTION/EJECTION

1.1.9.1 Transport Lines

1.1.9.1.2 Booster-SPEAR 3.0 GeV

*** MATERIALS ***	Unit	# of Units	Unit Cost	Cost Base	Total $
Bend Magnets	each	3	8867	SP86	26601
Quadrupoles	each	6	3981	SP86	23886
Steering Magnets	each	8	400	EU	3200
Supports	each	9	600	EU	5400
Contract Labor	hr	400	JL	EU	7180
Hoses	each	72	5	A86	360
Termials/Brackets	set	9	102	A86	918
Misc. Materials	lot	1	500	EU	500
	Subtotal straight SPEAR Inj.:				68045
Bend Magnets	each	10	8867	SP86	88670
Quadrupoles	each	10	3981	SP86	39810
Steering Magnets	each	12	400	EU	4800
Supports	each	20	600	EU	12000
Contract Labor	hr	1200	JL	EU	21541
Hoses	each	160	5	A86	800
Termials/Brackets	set	20	102	A86	2040
Misc. Materials	lot	1	1000	EU	1000
	Subtotal East Pit Injection:				170661
Total Materials					238707

*** LABOR ***	# of Units	Units MM	Total MM	Craft Code	Total Labor
	1	4	4	ME	30879
	1	3	3	TM	19474
	3	3	9	DB	84060
Total Labor					134413
Total 1.1.9.1.2					373120

1.1.9 INJECTION/EJECTION

1.1.9.1 Transport Lines

1.1.9.1.3 Power Supplies

*** MATERIALS ***	Unit	# of Units	Unit Cost	Cost Base	Total $
Bend Supply	kW	150	480	SLC	72000
Quad Supplies	each	13	1600	A86	20800
Trim Supplies	each	18	800	SP86	14400
Racks	each	5	2000	A86	10000
Trim Cabling	100 ft	60	60	EU	3600
Contract Labor	hr	1700	JL	EU	30517
Misc. Materials	lot	1	2000	EU	2000
Cabling/Pulling/Term.	each	6	5000	EU	30000
Total Materials					183317

*** LABOR ***	# of Units	Units Hours	Total MM	Craft Code	Total Labor
	1	80	0.46	ME	3570
	1	160	0.92	TM	6004
	1	240	1.39	CS	7288
Total Labor					16862
Total 1.1.9.1.3					200179

1.1.9 INJECTION/EJECTION

1.1.9.1 Transport Lines

1.1.9.1.4 Vacuum System

*** MATERIALS ***	Unit	# of Units	Unit Cost	Cost Base	Total $
Chamber	m	100	500	EU	50000
Position Monitors	each	9	950	SLC	8550
Roughing System	each	3	1381	CP	4143
Pressure Monitoring	each	3	1332	CP	3996
Supports	m	100	150	EU	15000
Misc. Materials	lot	1	1379	EU	1379
misc.Valves/Flanges/Bolts	set	1	6800	EU	6800
Mobile Mechanical Pump	each	1	2350	CP	2350
Cleaning/Installation	lot	1	5000	EU	5000
Contract Labor	MM	8	JL	EU	24844
Total Materials					122062

*** LABOR ***	# of Units	Units hr	Total MM	Craft Code	Total Labor
	1	160	0.92	ME	7140
	1	960	5.55	TV	36021
	1	480	2.77	TO	12732
Total Labor					55893
Total 1.1.9.1.4					177956

1.1.9 Injection/Ejection

1.1.9.2 Pulsed Magnets

1.1.9.2.1 Kicker Magnets/Pulser

*** MATERIALS ***	Unit	# of Units	Unit Cost	Cost Base	Total $
Injection Kicker Magnet	each	1	6500	EU	6500
Injection Kicker Pulser	each	1	5500	EU	5500
3GeV Kicker Booster/SPEAR	each	4	30000	EU	120000
3 GeV Kicker Pulser	each	4	40000	EU	160000
Misc. Materials	lot	1	3000	EU	3000
Contract Labor	MM	12	JL	EU	37267
Total Materials					332267

*** LABOR ***	# of Units	Units hr	Total MM	Craft Code	Total Labor
	1	2	2	EE	15271
	1	4	4	TE	16984
	1	2	2	ME	11580
	1	4	4	TM	25965
Total Labor					69799

Total 1.1.9.2.1	402066

1.1.9.2 Pulsed Magnets

1.1.9.2.2 Septa Magnets

*** MATERIALS ***	Unit	# of Units	Unit Cost	Cost Base	Total $
Booster Injection	each	1	5000	EU	5000
Booster Ejection	each	1	25000	EU	25000
SPEAR Injection	each	1	25000	EU	25000
Supports	each	3	2000	EU	6000
Power Supplies	each	3	6600	A86	19800
Misc. Materials	lot	1	2000	EU	2000
Contract Labor	hr	1086	JL	EU	19495
Total Materials					102295

*** LABOR ***	# of Units	Units hr	Total MM	Craft Code	Total Labor
	1	120	0.69	ME	5355
	1	960	5.55	TM	36021
Total Labor					41376

Total 1.1.9.2.2	143671

1.1.9 Injection/Ejection

1.1.9.3 Instrumentation (including Electronics)

*** MATERIALS ***	Unit	# of Units	Unit Cost	Cost Base	Total $
Gap Monitors	each	2	1060	SLC	2120
Profile Monitor	each	1	1340	SLC	1340
Faraday Cup	each	1	2680	SLC	2680
Misc. Materials	lot	1	500	EU	500
BPM Electronics	each	9	1250	SLC	11250
Contract Labor	hr	950	JL	SLC	17054
Total Materials					34944

*** LABOR ***	# of Units	Units hr	Total MM	Craft Code	Total Labor
	1	80	0.46	EE	3531
	1	120	0.69	TE	2945
Total Labor					6476

Total 1.1.9.3	41420

[illegible] estimate

	M+S	Constr.	ED+I	Total
Extr. Kicker mech. [illegible]	29.2	15.3	6.6	51.2
Inj. Kicker (M) 0.2m [illegible] 338G, 0.2m	6.4	5.5	6.64	18.6
Inj. Kicker PS	46.2	48.7	24.9	120.4
Extr. Kicker PS	54.1	53.3	24.9	132.3
59 beam bump (M) (pulsed beam bump?)	36.2	31.9	11.6	78.39

Extr. Septum (M) pulsed septs, 10 kG, 0.75m	70.0	0.0	0.0	70
Inj. Septum (M)	30.0	0.0	0.0	30
Inj. S.V. PS	60	0.0	0.0	60
Extr. S.V. PS	60	0.0	0.0	60
DC-Sept.	70	0.0	0.0	70

[illegible]

	I	E	
[illegible]	22.7	43.2	max
[illegible]	43.2	22.2	
[illegible]	19	12	
[illegible]	34	40	kV

BNL - 6 GeV Ring Estimate

3 GeV

[illegible]: 397.6

[illegible] 130

[illegible] 6

[illegible] 130

5[illegible]

[illegible]

2 GeV

Inj. [illegible] 95

[illegible] 39

184

[illegible] 10% [illegible] 321

505

[illegible] - 45

[illegible] - 51

409

200 MeV

Inj. Ki. M 12.6

PS 120

132.6

SSRL: 478 k$

APS: [illegible] 132 [illegible] 248

[illegible]

BEND MAGNETS for Transport Line

Take 3 SPRL magnets:

Steel	3 × 1789.6 =	5368.8	
Coils	same as for SPRL little longer easy shape. =	3172.0	includes assembly
		8540.8	
misc. mat		326.-	
		8866.8	take for injector

QUADRUPOLES

same as SPRL - QF

		injector (weaker magnet by factor 8/2.9)	
Steel	2004	1800	less iron
Coils	2600	1950	less Cu
misc. materials		231	
		3981	

TRANPORT LINE

Damping ring Estimates (1983)

position monitor (D WRIGHT / NADEAN) 00$ for Damping Ring (1983)

Profile Monitor (9) (D. WALZ / W D-W)	$1125	"
Scrapers (2)	"	6100
Spectrum Monitor (2)	"	5300
Faraday Cup (2)	"	2250
SLM (1)	"	16,000
Toroid/Gap Mon (6)	"	890
		58765

no add. cost for I+C

1.2 Project Management and Administration

1.2.1 Technical Project Management

1.2.1.1 Technical Coordination

*** MATERIALS ***	Unit	# of Units	Unit Cost	Cost Base	Total $
PC's	each	3	4500	CP	13500
CAD Licence	each	2	700	CP	1400
Computer Terminals	each	6	1500	CP	9000
Drafting Supplies/Velums	lot	1	8000	SP86	8000
Vendor Liaison/QC	all	1	11750	EU	11750
Standard Equipment	lot	1	15000	EU	15000
Drafting Boards	each	4	1500	CP	6000
Software	each	1	1398	CP	1398
Total Materials					66048

*** LABOR ***	# of Units	Units MM	Total MM	Craft Code	Total Labor
Project Director	1	21	21	SC	229214
Project Coordinator	1	12	12	CP	102159
Consultants	1	3	3	CN	22516
Total Labor					353888

Total 1.2.1.1	419936

VENDOR LIAISON

2 local trips/week for 2 years @$30

100 × 2 × 30 = $6000

5 area trips (LA etc)

5 × 350 = 1750

4 trips to east coast

4 × 1000 = 4000

11750

M.COX SPRL

ALIGNMENT

Scale	1378	CP	Jasper Eng.
TRIPODS	795	"	Silent Machine
INST STAND	1160	"	"
TARGET	40	"	BRinson Inst,
BUBBLES	502	"	"
ADAPTER	1613	"	Jasper
Align Stand	50	"	
Mounin.	55	"	
Scale Holder	88	CP	
Instr. Stands	500	EU	
Align Equip.	1087	CP	DRUSON
"	8563	CP	Haselbad Survey
Theodolite	23065	CP	Kern Inst,
Alg. Mounin.	1200	CP	Jasper Eng, Bear Fab
Precision Lift	3436	CP	
Algn. Tools	8132	CP	BRUNSON
	51664		
Machine Parts	8000		RT Enterprize
tall tripod (3)	4500		
Lighting general	[illegible]500		
for collimation	2000		
	66664		
Barricades	350		
	67014		

1.2 Project Management and Administration
1.2.1 Technical Project Management
1.2.1.2 Accelerator Physics

*** MATERIALS ***	Unit	# of Units	Unit Cost	Cost Base	Total $
Research Associate	each	1.50	3000	SSRL	4500
Graduate Students	each	3.00	1800	SSRL	5400
Total Materials					9900

*** LABOR ***	# of Units	Units MM	Total MM	Craft Code	Total Labor
Research Associate	1	12	12	RA	76683
Graduate Students	3	18	54	ST	86269
Total Labor					162952

Total 1.2.1.2					172852

1.2 Project Management and Administration
1.2.1 Technical Project Management
1.2.1.3 Quality Control and Installation Coordination

*** MATERIALS ***	Unit	# of Units	Unit Cost	Cost Base	Total $
PC's	each	2	4500	CP	9000
Alignment Instruments	lot	1	43935	CP	43935
Theodolite	each	1	23065	CP	23065
Equipm. for Qual. Control	lot	1	15000	EU	15000
Documentation/Files etc	lot	1	3500	EU	3500
Fork Lift 7-ton	each	1	30000	CP	30000
Contract Labor	MM	30	JL	EU	93167
Total Materials					217667

*** LABOR ***	# of Units	Units MM	Total MM	Craft Code	Total Labor
Mechanical Engineer	1	9	9	ME	69478
Electrical Engineer	1	9	9	EE	68719
Technician	1	24	24	TO	110136
Systems Coordinators	1	15	15	CS	78806
Electrical Designer	1	3	3	ED	16462
Mechanical Designer	1	3	3	MD	16462
Documentation Clerk	1	9	9	DC	24703
Total Labor					384766

Total 1.2.1.3	602433

1.2 Project Management and Administration
1.2.2 Administrative Services
1.2.2.1 Project Planning and Budget Office

*** MATERIALS ***	Unit	# of Units	Unit Cost	Cost Base	Total $
Construction Reviews	each	6	1500	EU	9000
Office Supplies	month	36	500	EU	18000
Pubs/Reports/Conferences	all	1	10000	EU	10000
Computer Software	lot	1	3000	CP	3000
PC	each	1	4500	CP	4500
Total Materials					44500

*** LABOR ***	# of Units	Units MM	Total MM	Craft Code	Total Labor
Admin. Assistant	1	36	36	AA	164432
Data Aid	1	18	18	DA	47863
Total Labor					212294

Total 1.2.2.1	256794

1.2 Project Management and Administration
1.2.2 Administrative Services
1.2.2.2 SSRL Administrative Services

*** MATERIALS ***	Unit	# of Units	Unit Cost	Cost Base	Total $
Total Materials					

*** LABOR ***	# of Units	Units MM	Total MM	Craft Code	Total Labor
Contract Serv. Manag.	1	3	3	AC	33259
Financial Admin.	1	6	6	AF	33066
Personnel Admin.	1	9	9	AP	41301
Total Labor					107627
Total 1.2.2.2					107627

APPENDIX

Appendix

Detailed

Booster Lattice Information

```
                                   *** PROGRAM P A T R I C I A 85.5  ***                      29-JUL-87      17:07:27


         THIS VERSION OF PATRICIA ALLOWS :
                                                A MAXIMUM OF  1000 ELEMENTS PER SUPERPERIOD
                                                A MAXIMUM OF   200 DIFFERENT ELEMENTS AND
                                                A MAXIMUM OF   300 MULTIPOLE MAGNETS PER SUPERPERIOD
**************************************************************************************************************


                                          INPUT-DATA FOR THE PROGRAM  PATRICIA
                                          ====================================


**************************************************************************************************************

         3 GEV BOOSTER

**************************************************************************************************************

$PARAM
ENERGY  =   3.000000000000000     ,
EN0     =   1.500000000000000     ,
DEN     =  0.5000000000000000     ,
CHROMX  =  0.0000000000000000E+00,
CHROMY  =  0.0000000000000000E+00,
HARM    =         120,
NSUP    =           1,
SYM     = T,
DELMAX  =   2.500000000000000     ,
NHAR    =         200,
RFV     =  0.0000000000000000E+00,
TQU     =  1.7000000000000000E-03,
TRACE   = F,
BETX0   =   1.000000000000000     ,
ALX0    =  0.0000000000000000E+00,
ETAX0   =  0.0000000000000000E+00,
ETXP0   =  0.0000000000000000E+00,
BETY0   =   1.000000000000000     ,
ALY0    =  0.0000000000000000E+00,
ETAY0   =  0.0000000000000000E+00,
ETYP0   =  0.0000000000000000E+00,
PETROS  =  0.0000000000000000E+00,
PROTON  = F
$END
$TRP
TURNS   =          10,
TRACK   = T,
TRSYN   = F,
OFFEN   = F,
DAMP    = F,
JPRINT  =           1,
PLOTS   =   2.000000000000000     ,
SPECT   = F,
SCALEB  =  0.0000000000000000E+00,
DYNAP   = T
$END
           1   1   1   1   1   1   1   0   0   0   0   0   0   0   0   0
         -26.08080  26.08080   0.00000  31.88900   6.00000
                0     0 0            0.0000000D+00        0.0000000D+00  0.0  0.0     0.00000
        STRT    1     0 0            0.0000000D+00        0.0000000D+00  0.0  0.0     0.00000
          DR    1     0 0            0.0000000D+00        0.0000000D+00  0.0  0.0     0.00000
          L0    1     0 0            0.1250000D+00        0.0000000D+00  0.0  0.0     0.00000
          L1    1     0 0            0.2500000D+00        0.0000000D+00  0.0  0.0     0.00000
         L2A    1     0 0            0.2000000D+01        0.0000000D+00  0.0  0.0     0.00000
         L2B    1     0 0            0.3000000D+01        0.0000000D+00  0.0  0.0     0.00000
          L3    1     0 0            0.7500000D+00        0.0000000D+00  0.0  0.0     0.00000
          L4    1     0 0            0.3500000D+00        0.0000000D+00  0.0  0.0     0.00000
          L5    1     0 0            0.1500000D+00        0.0000000D+00  0.0  0.0     0.00000
          L6    1     0 0            0.5000000D+00        0.0000000D+00  0.0  0.0     0.00000
           B    2     0 0            0.2000000D+01       -0.7639437D+01 30.0 17.0     0.00000
          B1    2     0 0            0.1200000D+01       -0.7639437D+01 30.0 17.0     0.00000
          B2    2     0 0            0.1200000D+01       -0.1145915D+02 30.0 17.0     0.00000
         QDH    3     0 0            0.1436000D+00        0.1447811D+01 30.0 30.0     0.00000
         QFH    3     0 0            0.1436000D+00       -0.1976623D+01 30.0 30.0     0.00000
          SF    4     0 0            0.0000000D+00        0.0000000D+00  0.0  0.0     0.00000
          SD    4     0 0            0.0000000D+00        0.0000000D+00  0.0  0.0     0.00000
        END     0     0 0            0.0000000D+00        0.0000000D+00  0.0  0.0     0.00000
        STRT
           1   0   0   0   0   0   0   0   0   0   0   0   0   0   0   0   0   0   0   0
```

```
QDH  L0  SD  L0   B  L1 QFH QFH  L0  SF  L0   B  L1 QDH
  1   1   1   1   1   1   1   1   1   1   1   1   1   1   0   0   0   0   0   0
QDH  L0  SD  L0   B  L1 QFH QFH  L0  SF  L0   B  L1 QDH
  1   1   1   1   1   1   1   1   1   1   1   1   1   1   0   0   0   0   0   0
QDH  L5  SD  L6  B1  L6  L5 QFH QFH  L5  SF  L6  B1  L6  L5 QDH
  1   1   1   1   1   1   1   1   1   1   1   1   1   1   1   1   0   0   0   0
QDH  L6  L6  B2  L5  L5  L5 QFH QFH  L4  L6  B2  L5  L5 QDH
  1   1   1   1   1   1   1   1   1   1   1   1   1   1   1   1   1   1   1   0
QDH L2B QFH
  1   1   1   0   0   0   0   0   0   0   0   0   0   0   0   0   0   0   0   0
QFH L2A QDH
  1   1   1   0   0   0   0   0   0   0   0   0   0   0   0   0   0   0   0   0
QDH  L5  L5  B2  L6  L6  DR QFH QFH  L5  L5  B2  L6  L6 QDH
  1   1   1   1   1   1   1   1   1   1   1   1   1   1   1   0   0   0   0   0
QDH  L5  L6  B1  L6  L5 QFH QFH  L5  SF  L6  B1  L6  L5 QDH
  1   1   1   1   1   1   1   1   1   1   1   1   1   1   1   1   0   0   0   0
QDH  L0  SD  L0   B  L1 QFH QFH  L0  SF  L0   B  L1 QDH
  1   1   1   1   1   1   1   1   1   1   1   1   1   1   0   0   0   0   0   0
QDH  L0  SD  L0   B  L1 QFH QFH  L0  SF  L0   B  L1 QDH
  1   1   1   1   1   1   1   1   1   1   1   1   1   1   0   0   0   0   0   0
  0.00000    0.00000    0.00000    0.00000    0.00000    0.00000    0.00000    0.00000
  0.00000
------------------------------------------------------------------------------------REAL-TIME SO FAR =         3. SEC
```

```
               *** PROGRAM P A T R I C I A 85.5  ***                    29-JUL-87      17:07:30

          3 GEV BOOSTER

******************************************************************************          KW(1)= 1

LATTICE-PARAMETER      UNITS: RHO(M),K(1/M**2),SM(1/M**2),FDRIF(M),LENGTH(M),LTOT(M)

    NR        TYP            RHO-K-SM           GRADIENT        FDRIF        LENGTH          LTOT


     1       STRT           0.0000000          0.0000000       0.00000      0.00000       0.00000
     2        QDH           1.4478109          0.0000000       0.00000      0.14360       0.14360
     3         L0           0.0000000          0.0000000       0.00000      0.12500       0.26860
     4         SD           0.0000000          0.0000000       0.00000      0.00000       0.26860
     5         L0           0.0000000          0.0000000       0.00000      0.12500       0.39360
     6          B          -7.6394373          0.0000000       0.00000      2.00000       2.39360
     7         L1           0.0000000          0.0000000       0.00000      0.25000       2.64360
     8        QFH          -1.9766225          0.0000000       0.00000      0.14360       2.78720
     9        QFH          -1.9766225          0.0000000       0.00000      0.14360       2.93080
    10         L0           0.0000000          0.0000000       0.00000      0.12500       3.05580
    11         SF           0.0000000          0.0000000       0.00000      0.00000       3.05580
    12         L0           0.0000000          0.0000000       0.00000      0.12500       3.18080
    13          B          -7.6394373          0.0000000       0.00000      2.00000       5.18080
    14         L1           0.0000000          0.0000000       0.00000      0.25000       5.43080
    15        QDH           1.4478109          0.0000000       0.00000      0.14360       5.57440
    16        QDH           1.4478109          0.0000000       0.00000      0.14360       5.71800
    17         L0           0.0000000          0.0000000       0.00000      0.12500       5.84300
    18         SD           0.0000000          0.0000000       0.00000      0.00000       5.84300
    19         L0           0.0000000          0.0000000       0.00000      0.12500       5.96800
    20          B          -7.6394373          0.0000000       0.00000      2.00000       7.96800
    21         L1           0.0000000          0.0000000       0.00000      0.25000       8.21800
    22        QFH          -1.9766225          0.0000000       0.00000      0.14360       8.36160
    23        QFH          -1.9766225          0.0000000       0.00000      0.14360       8.50520
    24         L0           0.0000000          0.0000000       0.00000      0.12500       8.63020
    25         SF           0.0000000          0.0000000       0.00000      0.00000       8.63020
    26         L0           0.0000000          0.0000000       0.00000      0.12500       8.75520
    27          B          -7.6394373          0.0000000       0.00000      2.00000      10.75520
    28         L1           0.0000000          0.0000000       0.00000      0.25000      11.00520
    29        QDH           1.4478109          0.0000000       0.00000      0.14360      11.14880
    30        QDH           1.4478109          0.0000000       0.00000      0.14360      11.29240
    31         L5           0.0000000          0.0000000       0.00000      0.15000      11.44240
    32         SD           0.0000000          0.0000000       0.00000      0.00000      11.44240
    33         L6           0.0000000          0.0000000       0.00000      0.50000      11.94240
    34         B1          -7.6394373          0.0000000       0.00000      1.20000      13.14240
    35         L6           0.0000000          0.0000000       0.00000      0.50000      13.64240
    36         L5           0.0000000          0.0000000       0.00000      0.15000      13.79240
    37        QFH          -1.9766225          0.0000000       0.00000      0.14360      13.93600
    38        QFH          -1.9766225          0.0000000       0.00000      0.14360      14.07960
    39         L5           0.0000000          0.0000000       0.00000      0.15000      14.22960
    40         SF           0.0000000          0.0000000       0.00000      0.00000      14.22960
    41         L6           0.0000000          0.0000000       0.00000      0.50000      14.72960
    42         B1          -7.6394373          0.0000000       0.00000      1.20000      15.92960
    43         L6           0.0000000          0.0000000       0.00000      0.50000      16.42960
    44         L5           0.0000000          0.0000000       0.00000      0.15000      16.57960
    45        QDH           1.4478109          0.0000000       0.00000      0.14360      16.72320
    46        QDH           1.4478109          0.0000000       0.00000      0.14360      16.86680
    47         L6           0.0000000          0.0000000       0.00000      0.50000      17.36680
    48         L6           0.0000000          0.0000000       0.00000      0.50000      17.86680
    49         B2         -11.4591500          0.0000000       0.00000      1.20000      19.06680
    50         L5           0.0000000          0.0000000       0.00000      0.15000      19.21680
    51         L5           0.0000000          0.0000000       0.00000      0.15000      19.36680
    52         L5           0.0000000          0.0000000       0.00000      0.15000      19.51680
    53        QFH          -1.9766225          0.0000000       0.00000      0.14360      19.66040
    54        QFH          -1.9766225          0.0000000       0.00000      0.14360      19.80400
    55         L4           0.0000000          0.0000000       0.00000      0.35000      20.15400
    56         L6           0.0000000          0.0000000       0.00000      0.50000      20.65400
    57         B2         -11.4591500          0.0000000       0.00000      1.20000      21.85400
    58         L5           0.0000000          0.0000000       0.00000      0.15000      22.00400
    59         L5           0.0000000          0.0000000       0.00000      0.15000      22.15400
    60        QDH           1.4478109          0.0000000       0.00000      0.14360      22.29760
    61        QDH           1.4478109          0.0000000       0.00000      0.14360      22.44120
    62        L2B           0.0000000          0.0000000       0.00000      3.00000      25.44120
    63        QFH          -1.9766225          0.0000000       0.00000      0.14360      25.58480
    64        QFH          -1.9766225          0.0000000       0.00000      0.14360      25.72840
    65        L2A           0.0000000          0.0000000       0.00000      2.00000      27.72840
    66        QDH           1.4478109          0.0000000       0.00000      0.14360      27.87200
    67        QDH           1.4478109          0.0000000       0.00000      0.14360      28.01560
    68         L5           0.0000000          0.0000000       0.00000      0.15000      28.16560
    69         L5           0.0000000          0.0000000       0.00000      0.15000      28.31560
    70         B2         -11.4591500          0.0000000       0.00000      1.20000      29.51560
```

```
    71      L6       0.0000000      0.0000000      0.00000      0.50000      30.01560
    72      L6       0.0000000      0.0000000      0.00000      0.50000      30.51560
    73      DR       0.0000000      0.0000000      0.00000      0.00000      30.51560
    74     QFH      -1.9766225      0.0000000      0.00000      0.14360      30.65920
    75     QFH      -1.9766225      0.0000000      0.00000      0.14360      30.80280
    76      L5       0.0000000      0.0000000      0.00000      0.15000      30.95280
    77      L5       0.0000000      0.0000000      0.00000      0.15000      31.10280
    78      B2     -11.4591500      0.0000000      0.00000      1.20000      32.30280
    79      L6       0.0000000      0.0000000      0.00000      0.50000      32.80280
    80      L6       0.0000000      0.0000000      0.00000      0.50000      33.30280
    81     QDH       1.4478109      0.0000000      0.00000      0.14360      33.44640
    82     QDH       1.4478109      0.0000000      0.00000      0.14360      33.59000
    83      L5       0.0000000      0.0000000      0.00000      0.15000      33.74000
    84      L6       0.0000000      0.0000000      0.00000      0.50000      34.24000
    85      B1      -7.6394373      0.0000000      0.00000      1.20000      35.44000
    86      L6       0.0000000      0.0000000      0.00000      0.50000      35.94000
    87      L5       0.0000000      0.0000000      0.00000      0.15000      36.09000
    88     QFH      -1.9766225      0.0000000      0.00000      0.14360      36.23360
    89     QFH      -1.9766225      0.0000000      0.00000      0.14360      36.37720
    90      L5       0.0000000      0.0000000      0.00000      0.15000      36.52720
    91      SF       0.0000000      0.0000000      0.00000      0.00000      36.52720
    92      L6       0.0000000      0.0000000      0.00000      0.50000      37.02720
    93      B1      -7.6394373      0.0000000      0.00000      1.20000      38.22720
    94      L6       0.0000000      0.0000000      0.00000      0.50000      38.72720
    95      L5       0.0000000      0.0000000      0.00000      0.15000      38.87720
    96     QDH       1.4478109      0.0000000      0.00000      0.14360      39.02080
    97     QDH       1.4478109      0.0000000      0.00000      0.14360      39.16440
    98      L0       0.0000000      0.0000000      0.00000      0.12500      39.28940
    99      SD       0.0000000      0.0000000      0.00000      0.00000      39.28940
   100      L0       0.0000000      0.0000000      0.00000      0.12500      39.41440
   101       B      -7.6394373      0.0000000      0.00000      2.00000      41.41440
   102      L1       0.0000000      0.0000000      0.00000      0.25000      41.66440
   103     QFH      -1.9766225      0.0000000      0.00000      0.14360      41.80800
   104     QFH      -1.9766225      0.0000000      0.00000      0.14360      41.95160
   105      L0       0.0000000      0.0000000      0.00000      0.12500      42.07660
   106      SF       0.0000000      0.0000000      0.00000      0.00000      42.07660
   107      L0       0.0000000      0.0000000      0.00000      0.12500      42.20160
   108       B      -7.6394373      0.0000000      0.00000      2.00000      44.20160
   109      L1       0.0000000      0.0000000      0.00000      0.25000      44.45160
   110     QDH       1.4478109      0.0000000      0.00000      0.14360      44.59520
   111     QDH       1.4478109      0.0000000      0.00000      0.14360      44.73880
   112      L0       0.0000000      0.0000000      0.00000      0.12500      44.86380
   113      SD       0.0000000      0.0000000      0.00000      0.00000      44.86380
   114      L0       0.0000000      0.0000000      0.00000      0.12500      44.98880
   115       B      -7.6394373      0.0000000      0.00000      2.00000      46.98880
   116      L1       0.0000000      0.0000000      0.00000      0.25000      47.23880
   117     QFH      -1.9766225      0.0000000      0.00000      0.14360      47.38240
   118     QFH      -1.9766225      0.0000000      0.00000      0.14360      47.52600
   119      L0       0.0000000      0.0000000      0.00000      0.12500      47.65100
   120      SF       0.0000000      0.0000000      0.00000      0.00000      47.65100
   121      L0       0.0000000      0.0000000      0.00000      0.12500      47.77600
   122       B      -7.6394373      0.0000000      0.00000      2.00000      49.77600
   123      L1       0.0000000      0.0000000      0.00000      0.25000      50.02600
   124     QDH       1.4478109      0.0000000      0.00000      0.14360      50.16960
-----------------------------------------------------------------------REAL-TIME SO FAR =        4. SEC
```

```
TRANSFORMATION MATRICES

MATRIX-X                                                 MATRIX-Y                         DP/P =      0.00000E+00

 0.02851126   1.61029576   0.76786803                   0.47575345   6.29003134   0.00000000
-0.62049912   0.02851126   0.49044463                  -0.12299758   0.47575345   0.00000000
 0.00000000   0.00000000   1.00000000                   0.00000000   0.00000000   1.00000000

PERIODIC LATTICE FUNCTIONS

 BETA-X =     1.61095 M    ALPHA-X =     0.00000
 BETY-Y =     7.15119 M    ALPHA-Y =     0.00000
 ETA-X  =     0.79040 M    ETAP-X  =     0.00000 RAD
 ETA-Y  =     0.00000 M    ETAP-Y  =     0.00000 RAD

------------------------------------------------------------------------------REAL-TIME SO FAR =         5. SEC
```

```
                                   M I T T E L W E R T E                      *** PROGRAM P A T R I C I A 85.5  ***
                                   *********************
                                   DP/P =     0.00000E+00                                       KW(2) =  1

DEFINITION: <FUNCT> = INTEGRAL OF FUNCT ALONG NSUP SUPERPERIODS DIVIDED BY TOTAL INTEGRATION LENGTH
CHROMATIC TERMS (SEE H.WIEDEMANN DESY H5/71-10)


ELECTRON STORAGE RING PARAMETERS

    CIRCUMFERENCE (M)               100.33920               REVOLUTIONFREQUENCY (KHZ)          2987.79
    RF-FREQUENCY (MHZ)              358.53485               HARMONIC NUMBER                     120
    MOMENTUM COMPACTION FACTOR        0.0540384             NAT.EMITTANCE(HORIZ)(RAD*M)          5.307E-08 * E(GEV))**2
    ENERGYSPREAD (%)                  0.0305393 * E(GEV)    TRANSITION ENERGY                    4.30179
    DAMPING PARTITION NUMBERS JS=  2.000
                              JX=  1.000
                              JY=  1.000


RADIATION AND OTHER INTEGRALS (SEE R.H.HELM ET AL. SLAC-PUB-1193 AND H.WIEDEMANN PEP-NOTE 39 :)

   <K*BETAX> =                                                 -0.79855E+00       <-K*BETAY> =            0.63690E+00
   <DX/R>+<DDX/R>*DP/P =                                        0.54038E-01       <BETAX =                4.3902 M
   <1/R**2> =                                                   0.78326E-02       <BETAY> =               6.3178 M
   <1/R**3> =                                                   0.99349E-03       <GAMAX> =               0.8059 1/M
   <(GAMMAX*DX**2+BETAX*DPX**2+2*ALPHAX*DPX*DX)/R**3> =          0.28268E-03       <GAMAY> =               0.5882 1/M
   <(GAMMAY*DY**2+BETAY*DPY**2+2*ALPHAY*DPY*DY)/R**3> =          0.00000E+00       <ETAX> =                0.6907 M
   <2*K**2*DX**2>/<1/R**2> =                                    0.77153E+02       <ETAXP**2> =            0.56070E-01
   <DX*(ISEC/R**3-2*K/R)> =                                     0.00000E+00       <ETAYP**2> =            0.00000E+00
   <DY*(ISEC/R**3+2*K/R)> =                                     0.00000E+00       <(ETAX/R)**2> =         0.70256E-02
                                                                                  <(ETAY/R)**2> =         0.00000E+00


MOMENTUM (GEV/C)                  3.000     1.500     2.000     2.500     3.000     3.500     4.000     4.500     5.000
-----------------------------------------------------------------------------------------------------------------------
ENERGYLOSS/TURN (MEV)             0.896     0.056     0.177     0.432     0.896     1.660     2.833     4.537     6.915
RF-PHASE (DEGREE)                29.852    21.130    24.646    27.482    29.852    31.645    32.880    34.137    35.126
RF-VOLTAGE (MVOLT)                1.801     0.155     0.425     0.937     1.801     3.165     5.218     8.085    12.019
SYNCHR.FREQUENCY (KC)            69.252    29.837    42.160    55.337    69.252    84.213   100.461   117.053   134.586
SYNCHROTRON TUNE (1/1000)        23.178     9.986    14.111    18.521    23.178    28.186    33.624    39.177    45.045
QUANTUMLIFETIME (HOURS)           0.002     0.019     0.008     0.004     0.002     0.002     0.002     0.002     0.002
SYNCH-DAMP-TIME (MSEC)            1.120     8.963     3.781     1.936     1.120     0.706     0.473     0.332     0.242
BET-DAMP-TIME-HOR (MSEC)          2.241    17.925     7.562     3.872     2.241     1.411     0.945     0.664     0.484
BET-DAMP-TIME-VER (MSEC)          2.241    17.925     7.562     3.872     2.241     1.411     0.945     0.664     0.484
NAT.EMITTANCE (RAD*M)          4.78E-07  1.19E-07  2.12E-07  3.32E-07  4.78E-07  6.50E-07  8.49E-07  1.07E-06  1.33E-06
BUNCHLENGTH (MM)                 34.111    39.586    37.354    35.574    34.111    32.726    31.352    30.271    29.253
BUNCHLENGTH (PSEC)              113.781   132.046   124.598   118.661   113.781   109.161   104.579   100.974    97.578
ENERGYSPREAD (PERCENT)            0.092     0.046     0.061     0.076     0.092     0.107     0.122     0.137     0.153


RING ACCEPTANCE FOR A MONOCHROMATIC BEAM IN MM*MRAD (DP/P =   0.000000)

                         EPSX-MAX =    69.43    LIMITED IN MAGNET  QFH AT J =    88    HALF APERTURE    30.00 MM
                         EPSY-MAX =    22.39    LIMITED IN MAGNET   B2 AT J =    57    HALF APERTURE    17.00 MM

------------------------------------------------------------------------------------REAL-TIME SO FAR =       13. SEC
------------------------------------------------------------------------------------REAL-TIME SO FAR =       13. SEC
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                                  B E A M - D Y N A M I C S - P A R A M E T E R          *** PROGRAM P A T R I C I A 85.5 ***
                                  *********************************************                      KW(3)= 1
                                                      DP/P =      0.00000E+00
       UNITS OF BETA,ETA AND LENGTH ARE METERS;BSC IS FOR 10 SIGMA-TOT;  PARAMETERS AT THE END OF ELEMENTS
MAGNET J    BETAX     ALFAX    BSCX(MM)    ETAX     DNUEX     BETAY     ALFAY    BSCY(MM)   ETAY     DNUEY          TOT-L
---------------------------------------------------------------------------------------------------------------------------

  STRT  1  1.61095   0.00000  11.37494  0.79040  0.00000   7.15119   0.00000  13.06883  0.00000  0.00000        0.0000
   QDH  2  1.67245  -0.43256  11.57188  0.80223  0.01401   6.94266   1.43767  12.87688  0.00000  0.00323        0.1436
    L0  3  1.79168  -0.52128  11.93397  0.82288  0.02551   6.59014   1.38245  12.54570  0.00000  0.00617        0.2686
    SD  4  1.79168  -0.52128  11.93397  0.82288  0.02551   6.59014   1.38245  12.54570  0.00000  0.00617        0.2686
    L0  5  1.93310  -0.61001  12.33133  0.84352  0.03621   6.25143   1.32724  12.21905  0.00000  0.00927        0.3936
     B  6  7.12026  -2.01344  22.62397  1.43036  0.12567   2.46895   0.49882   7.67899  0.00000  0.09428        2.3936
    L1  7  8.17134  -2.19089  24.26385  1.53748  0.13089   2.25116   0.37237   7.33248  0.00000  0.11118        2.6436
   QFH  8  8.46948   0.14298  24.71362  1.56736  0.13362   2.24487  -0.32797   7.32222  0.00000  0.12143        2.7872
   QFH  9  8.09143   2.45386  24.16424  1.53357  0.13636   2.44471  -1.08251   7.64119  0.00000  0.13126        2.9308
    L0 10  7.49152   2.34539  23.25672  1.47666  0.13891   2.72921  -1.19355   8.07358  0.00000  0.13896        3.0558
    SF 11  7.49152   2.34539  23.25672  1.47666  0.13891   2.72921  -1.19355   8.07358  0.00000  0.13896        3.0558
    L0 12  6.91873   2.23692  22.35350  1.41975  0.14168   3.04148  -1.30460   8.52296  0.00000  0.14587        3.1808
     B 13  1.46538   0.52115  11.00211  0.77986  0 24831  11.42749  -2.74389  16.52050  0.00000  0.20095        5.1808
    L1 14  1.25904   0.30421  10.25183  0.73187  0.27777  12.84608  -2.93047  17.51592  0.00000  0.20424        5.4308
   QDH 15  1.22596  -0.07155  10.07398  0.71511  0.29630  13.30658  -0.24435  17.82710  0.00000  0.20598        5.5744
   QDH 16  1.30096  -0.45594  10.27754  0.71976  0.31452  12.98366   2.47066  17.60947  0.00000  0.20771        5.7180
    L0 17  1.42945  -0.57200  10.64868  0.73312  0.32913  12.37454   2.40227  17.19144  0.00000  0.20928        5.8430
    SD 18  1.42945  -0.57200  10.64868  0.73312  0.32913  12.37454   2.40227  17.19144  0.00000  0.20928        5.8430
    L0 19  1.58696  -0.68805  11.07144  0.74648  0.34236  11.78253   2.33387  16.77517  0.00000  0.21092        5.9680
     B 20  7.93757  -2.52382  22.44304  1.21807  0.43640   4.15924   1.34640   9.96678  0.00000  0.25704        7.9680
    L1 21  9.25751  -2.75593  24.21531  1.31061  0.44104   3.52831   1.17733   9.17975  0.00000  0.26743        8.2180
   QFH 22  9.67433  -0.10718  24.74082  1.33678  0.44344   3.34083   0.14592   8.93254  0.00000  0.27413        8.3616
   QFH 23  9.31741   2.55881  24.26548  1.30866  0.44583   3.44220  -0.86138   9.06704  0.00000  0.28092        8.5052
    L0 24  8.69037   2.45755  23.42053  1.26071  0.44804   3.66545  -0.92463   9.35646  0.00000  0.28652        8.6302
    SF 25  8.69037   2.45755  23.42053  1.26071  0.44804   3.66545  -0.92463   9.35646  0.00000  0.28652        8.6302
    L0 26  8.08864   2.35630  22.57928  1.21277  0.45041   3.90452  -0.98789   9.65676  0.00000  0.29178        8.7552
     B 27  1.93756   0.75466  11.63714  0.71467  0.53365   9.47962  -1.70358  15.04677  0.00000  0.34510       10.7552
    L1 28  1.61086   0.55214  10.78362  0.68461  0.55624  10.35714  -1.80650  15.72779  0.00000  0.34911       11.0052
   QDH 29  1.51455   0.12518  10.52963  0.67750  0.57097  10.56796   0.35307  15.88705  0.00000  0.35129       11.1488
   QDH 30  1.53751  -0.28669  10.65280  0.69066  0.58604  10.15836   2.47088  15.57612  0.00000  0.35348       11.2924
    L5 31  1.63936  -0.39227  11.01042  0.71509  0.60110   9.43283   2.36596  15.00958  0.00000  0.35592       11.4424
    SD 32  1.63936  -0.39227  11.01042  0.71509  0.60110   9.43283   2.36596  15.00958  0.00000  0.35592       11.4424
    L6 33  2.20759  -0.74419  12.59775  0.79652  0.64343   7.24173   2.01624  13.15130  0.00000  0.36555       11.9424
    B1 34  4.99156  -1.58535  18.36520  1.08520  0.70205   3.29184   1.23464   8.86680  0.00000  0.40507       13.1424
    L6 35  6.75288  -1.93728  21.27762  1.24533  0.71577   2.24891   0.85122   7.32881  0.00000  0.43449       13.6424
    L5 36  7.34990  -2.04286  22.16961  1.29336  0.71916   2.01079   0.73619   6.92997  0.00000  0.44573       13.7924
   QFH 37  7.63958   0.05306  22.57376  1.31277  0.72219   1.89268   0.09750   6.72335  0.00000  0.45753       13.9360
   QFH 38  7.32024   2.14045  22.06676  1.27885  0.72522   1.95325  -0.52507   6.83010  0.00000  0.46951       14.0796
    L5 39  6.69526   2.02608  21.06890  1.21586  0.72863   2.12547  -0.62304   7.12484  0.00000  0.48124       14.2296
    SF 40  6.69526   2.02608  21.06890  1.21586  0.72863   2.12547  -0.62304   7.12484  0.00000  0.48124       14.2296
    L6 41  4.85980   1.64484  17.80640  1.00590  0.74260   2.91179  -0.94960   8.33926  0.00000  0.51344       14.7296
    B1 42  2.01737   0.73362  11.24234  0.59810  0.80493   6.03158  -1.61809  12.00227  0.00000  0.55966       15.9296
    L6 43  1.47437   0.35238   9.41908  0.46684  0.85174   7.79965  -1.91803  13.64851  0.00000  0.57128       16.4296
    L5 44  1.38581   0.23801   9.02955  0.42746  0.86847   8.38855  -2.00801  14.15439  0.00000  0.57423       16.5796
   QDH 45  1.37375  -0.15321   8.87583  0.39597  0.88515   8.71813  -0.26422  14.42977  0.00000  0.57689       16.7232
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MAGNET	J	BETAX	ALFAX	BSCX(MM)	ETAX	DNUEX	BETAY	ALFAY	BSCY(MM)	ETAY	DNUEY	TOT-L
QDH	46	1.47557	-0.56290	9.07584	0.37633	0.90131	8.53732	1.51082	14.27935	0.00000	0.57952	16.8668
L6	47	2.26158	-1.00912	10.81886	0.32780	0.94544	7.12263	1.31857	13.04271	0.00000	0.58974	17.3668
L6	48	3.49381	-1.45534	13.16945	0.27927	0.97390	5.90018	1.12632	11.87081	0.00000	0.60202	17.8668
B2	49	8.26067	-2.52431	19.97158	0.22578	1.00968	3.70094	0.69632	9.40164	0.00000	0.64336	19.0668
L5	50	9.03804	-2.65817	20.88158	0.22695	1.01245	3.50107	0.63614	9.14425	0.00000	0.64999	19.2168
L5	51	9.85557	-2.79204	21.79761	0.22811	1.01498	3.31925	0.57596	8.90365	0.00000	0.65700	19.3668
L5	52	10.71326	-2.92591	22.71893	0.22927	1.01730	3.15549	0.51578	8.68123	0.00000	0.66438	19.5168
QFH	53	11.11832	0.14361	23.13789	0.22572	1.01938	3.14206	-0.42100	8.66274	0.00000	0.67169	19.6604
QFH	54	10.63299	3.19004	22.62104	0.21300	1.02147	3.40394	-1.42735	9.01651	0.00000	0.67872	19.8040
L4	55	8.52873	2.82215	20.24472	0.17117	1.02732	4.51239	-1.73965	10.38128	0.00000	0.69296	20.1540
L6	56	5.96935	2.29660	16.91680	0.11141	1.03848	6.47511	-2.18580	12.43573	0.00000	0.70770	20.6540
B2	57	1.97563	1.03759	9.71855	0.03103	1.09519	12.90626	-3.14408	17.55690	0.00000	0.72865	21.8540
L5	58	1.68801	0.87992	8.98333	0.02883	1.10827	13.86847	-3.27060	18.19960	0.00000	0.73044	22.0040
L5	59	1.44768	0.72226	8.31928	0.02662	1.12357	14.86862	-3.39711	18.84443	0.00000	0.73210	22.1540
QDH	60	1.30164	0.30485	7.88841	0.02490	1.14033	15.40268	-0.28488	19.17988	0.00000	0.73360	22.2976
QDH	61	1.26907	-0.07579	7.78892	0.02392	1.15824	15.02902	2.86103	18.94580	0.00000	0.73510	22.4412
L2B	62	8.85639	-2.45331	20.56820	0.01104	1.33460	3.36350	1.02748	8.96280	0.00000	0.80442	25.4412
QFH	63	9.20200	0.07931	20.96564	0.01020	1.33711	3.21207	0.04135	8.75871	0.00000	0.81143	25.5848
QFH	64	8.81206	2.59918	20.51657	0.00895	1.33963	3.33910	-0.93794	8.93022	0.00000	0.81845	25.7284
L2A	65	1.93585	0.83892	9.61663	-0.01114	1.42009	9.34266	-2.06384	14.93767	0.00000	0.87674	27.7284
QDH	66	1.76679	0.35007	9.18735	-0.01276	1.43252	9.65899	-0.11710	15.18845	0.00000	0.87913	27.8720
QDH	67	1.73075	-0.09657	9.09342	-0.01476	1.44567	9.40859	1.84347	14.99029	0.00000	0.88152	28.0156
L5	68	1.77284	-0.18404	9.20364	-0.01707	1.45931	8.86607	1.77335	14.55168	0.00000	0.88413	28.1656
L5	69	1.84117	-0.27152	9.37967	-0.01937	1.47254	8.34458	1.70323	14.11724	0.00000	0.88691	28.3156
B2	70	3.32833	-0.97005	12.61093	0.02498	1.55293	4.86111	1.18373	10.77495	0.00000	0.91707	29.5156
L6	71	4.44417	-1.26163	14.58393	0.06970	1.57368	3.80086	0.93675	9.52771	0.00000	0.93563	30.0156
L6	72	5.85159	-1.55322	16.75143	0.11442	1.58931	2.98760	0.68977	8.44713	0.00000	0.95933	30.5156
DR	73	5.85159	-1.55322	16.75143	0.11442	1.58931	2.98760	0.68977	8.44713	0.00000	0.95933	30.5156
QFH	74	6.06223	0.10637	17.05524	0.12485	1.59312	2.91784	-0.19735	8.34792	0.00000	0.96713	30.6592
QFH	75	5.79214	1.74885	16.67617	0.13021	1.59695	3.10407	-1.11709	8.61020	0.00000	0.97478	30.8028
L5	76	5.28325	1.64374	15.93267	0.13307	1.60126	3.45549	-1.22572	9.08453	0.00000	0.98207	30.9528
L5	77	4.80590	1.53864	15.20239	0.13593	1.60600	3.83950	-1.33435	9.57602	0.00000	0.98863	31.1028
B2	78	2.12520	0.69936	10.27777	0.22151	1.66715	8.02514	-2.13455	13.84439	0.00000	1.02331	32.3028
L6	79	1.60102	0.34901	9.12243	0.28344	1.71084	10.33278	-2.48072	15.70927	0.00000	1.03205	32.8028
L6	80	1.42718	-0.00133	8.84214	0.34536	1.76449	12.98659	-2.82690	17.61145	0.00000	1.03892	33.3028
QDH	81	1.48519	-0.40670	9.07388	0.36841	1.78029	13.41268	-0.11067	17.89803	0.00000	1.04064	33.4464
QDH	82	1.66546	-0.86113	9.65146	0.40248	1.79492	13.04890	2.61865	17.65365	0.00000	1.04236	33.5900
L5	83	1.94733	-1.01798	10.46785	0.44415	1.80819	12.27686	2.52833	17.12345	0.00000	1.04425	33.7400
L6	84	3.22673	-1.54082	13.51536	0.58305	1.84015	9.89907	2.22725	15.37605	0.00000	1.05147	34.2400
B1	85	8.40294	-2.79048	22.06479	1.00911	1.87700	5.24359	1.60435	11.19082	0.00000	1.07810	35.4400
L6	86	11.45484	-3.31332	25.95134	1.22671	1.88512	3.80963	1.26356	9.53870	0.00000	1.09595	35.9400
L5	87	12.47237	-3.47017	27.12706	1.29199	1.88712	3.44590	1.16132	9.07191	0.00000	1.10254	36.0900
QFH	88	12.96191	0.10756	27.69731	1.32782	1.88890	3.25985	0.15184	8.82361	0.00000	1.10940	36.2336
QFH	89	12.41225	3.66799	27.14547	1.30972	1.89069	3.35629	-0.83255	8.95318	0.00000	1.11636	36.3772
L5	90	11.33806	3.49331	25.98871	1.26270	1.89270	3.61740	-0.90822	9.29493	0.00000	1.12322	36.5272
SF	91	11.33806	3.49331	25.98871	1.26270	1.89270	3.61740	-0.90822	9.29493	0.00000	1.12322	36.5272
L6	92	8.13587	2.91106	22.16514	1.10596	1.90099	4.65174	-1.16045	10.54036	0.00000	1.14266	37.0272
B1	93	2.84117	1.51939	13.88884	0.82540	1.94097	8.01452	-1.60722	13.83523	0.00000	1.17415	38.2272
L6	94	1.61290	0.93714	11.13231	0.74737	1.97849	9.73351	-1.83076	15.24693	0.00000	1.18316	38.7272
L5	95	1.35796	0.76246	10.43357	0.72396	1.99465	10.29280	-1.89783	15.67886	0.00000	1.18555	38.8772
QDH	96	1.19980	0.34989	9.99477	0.71228	2.01269	10.53195	0.24903	15.85996	0.00000	1.18773	39.0208

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MAGNET J     BETAX     ALFAX    BSCX(MM)   ETAX      DNUEX     BETAY     ALFAY    BSCY(MM)   ETAY      DNUEY          TOT-L
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   QDH  97   1.15296  -0.02047   9.94069  0.72191   2.03226  10.15259   2.36645  15.57170  0.00000   1.18993      39.1644
    LO  98   1.17163  -0.12894  10.09359  0.73960   2.04941   9.57113   2.28518  15.11922  0.00000   1.19195      39.2894
    SD  99   1.17163  -0.12894  10.09359  0.73960   2.04941   9.57113   2.28518  15.11922  0.00000   1.19195      39.2894
    LO 100   1.21742  -0.23740  10.30979  0.75730   2.06610   9.00999   2.20392  14.66932  0.00000   1.19409      39.4144
     B 101   5.54843  -1.95304  20.15822  1.29756   2.20369   2.48811   0.94462   7.70872  0.00000   1.26350      41.4144
    L1 102   6.57918  -2.16996  21.87462  1.39878   2.21028   2.06333   0.75449   7.01992  0.00000   1.28110      41.6644
   QFH 103   6.93870  -0.29958  22.41949  1.42812   2.21364   1.94185   0.10292   6.81014  0.00000   1.29260      41.8080
   QFH 104   6.74662   1.61898  22.06021  1.39945   2.21696   2.00259  -0.53164   6.91583  0.00000   1.30428      41.9516
    LO 105   6.35026   1.55189  21.35822  1.34940   2.22000   2.14551  -0.61170   7.15835  0.00000   1.31388      42.0766
    SF 106   6.35026   1.55189  21.35822  1.34940   2.22000   2.14551  -0.61170   7.15835  0.00000   1.31388      42.0766
    LO 107   5.97067   1.48480  20.66194  1.29936   2.22323   2.30844  -0.69176   7.42518  0.00000   1.32283      42.2016
     B 108   2.19739   0.42356  12.42922  0.76811   2.31513   7.38567  -1.75936  13.28136  0.00000   1.40330      44.2016
    L1 109   2.01916   0.28938  11.90180  0.73385   2.33406   8.30000  -1.89798  14.07948  0.00000   1.40839      44.4516
   QDH 110   2.00645  -0.19998  11.83084  0.72506   2.34548   8.60029  -0.17235  14.33192  0.00000   1.41108      44.5952
   QDH 111   2.13633  -0.71347  12.15557  0.73797   2.35659   8.39704   1.57366  14.16155  0.00000   1.41375      44.7388
    LO 112   2.32573  -0.80177  12.62582  0.75871   2.36552   8.01009   1.52191  13.83141  0.00000   1.41618      44.8638
    SD 113   2.32573  -0.80177  12.62582  0.75871   2.36552   8.01009   1.52191  13.83141  0.00000   1.41618      44.8638
    LO 114   2.53721  -0.89006  13.12217  0.77946   2.37371   7.63608   1.47016  13.50464  0.00000   1.41872      44.9888
     B 115   8.81846  -2.28672  24.04769  1.36790   2.44234   3.09684   0.72124   8.60017  0.00000   1.48618      46.9888
    L1 116  10.00597  -2.46332  25.70264  1.47522   2.44658   2.76691   0.59852   8.12914  0.00000   1.49979      47.2388
   QFH 117  10.30641   0.39965  26.13045  1.50648   2.44882   2.71488  -0.23133   8.05236  0.00000   1.50819      47.3824
   QFH 118   9.78260   3.19835  25.50068  1.47655   2.45108   2.90342  -1.09941   8.32727  0.00000   1.51639      47.5260
    LO 119   9.00095   3.05486  24.49819  1.42403   2.45320   3.19016  -1.19450   8.72879  0.00000   1.52293      47.6510
    SF 120   9.00095   3.05486  24.49819  1.42403   2.45320   3.19016  -1.19450   8.72879  0.00000   1.52293      47.6510
    LO 121   8.25517   2.91137  23.49924  1.37151   2.45551   3.50067  -1.28959   9.14373  0.00000   1.52888      47.7760
     B 122   1.22990   0.64171  10.61204  0.80109   2.56205  11.28697  -2.46938  16.41861  0.00000   1.58042      49.7760
    L1 123   0.98078   0.35474   9.77610  0.76188   2.59859  12.56096  -2.62659  17.32045  0.00000   1.58376      50.0260
   QDH 124   0.93035   0.00000   9.57792  0.75065   2.62273  12.94194   0.00000  17.58115  0.00000   1.58554      50.1696
*************************************************************************************************************************************
             TUNES              NUEX =    5.24546    NUEY =    3.17109              DP/P =     0.00000E+00
*************************************************************************************************************************************
-----------------------------------------------------------------------------------------------REAL-TIME SO FAR =        16. SEC
```

```
   3 GEV BOOSTER

                                   **** MULTIPOLE-STRUCTURE IN ONE HALF-SUPERPERIOD ****

                               J  MULTIPOLE      <BETX(M)> <BETY(M)>  <PHIX>     <PHIY>     <ETAX(M)> SM(1/M**2)

  1. MULTIPOLE AT: J =     4      SD              1.792     6.590     0.026      0.006      0.823     1.43297
  2. MULTIPOLE AT: J =    11      SF              7.492     2.729     0.139      0.139      1.477    -0.74592
  3. MULTIPOLE AT: J =    18      SD              1.429    12.375     0.329      0.209      0.733     1.43297
  4. MULTIPOLE AT: J =    25      SF              8.690     3.665     0.448      0.287      1.261    -0.74592
  5. MULTIPOLE AT: J =    32      SD              1.639     9.433     0.601      0.356      0.715     1.43297
  6. MULTIPOLE AT: J =    40      SF              6.695     2.125     0.729      0.481      1.216    -0.74592
  7. MULTIPOLE AT: J =    91      SF             11.338     3.617     1.893      1.123      1.263    -0.74592
  8. MULTIPOLE AT: J =    99      SD              1.172     9.571     2.049      1.192      0.740     1.43297
  9. MULTIPOLE AT: J =   106      SF              6.350     2.146     2.220      1.314      1.349    -0.74592
 10. MULTIPOLE AT: J =   113      SD              2.326     8.010     2.366      1.416      0.759     1.43297
 11. MULTIPOLE AT: J =   120      SF              9.001     3.190     2.453      1.523      1.424    -0.74592

TOTAL NUMBER OF MULTIPOLES IN STORAGE RING:    22


                         WITHOUT SEXTUPOLES        WITH SPEC.SEXTUPOLES       WITH ALL SEXTUPOLES        CHROMATICITY WANTED
 CHROMATICITY IN X    =        -6.376          *         -6.376          *          0.000          *          0.000          *

 CHROMATICITY IN Y    =        -5.086          *         -5.086          *          0.000          *          0.000          *


                         TOTAL CORRECTED CHROMATICITY


 POSITIVE SEXTUPOLES: DCHX =   -1.44267          DCHY =    7.84462
 NEGATIVE SEXTUPOLES: DCHX =    7.81890          DCHY =   -2.75910
-------------------------------------------------------------------------------------REAL-TIME SO FAR =        17. SEC
```

```
TUNE SHIFT WITH AMPLITUDE (SEE H.WIEDEMANN PEP-NOTE 220)                                                        KW(4)= 1

HARM   JSEX    DAN(JSEX)    A-HARM    NUE-TERM  3NUE-TERM         HARM    JSEX  DAN(JSEX)   A-HARM     NUE-TERM  3NUE-TERM
  0     91       -57.        -184.      -17.
  1    120        39.          21.        0.        0.  **          2      120      -37.       -63.        -4.        0.
  3     91       -49.         -16.        0.        0.  **          4       91       53.        56.        -7.        0.
  5     25        34.          10.       -1.        0.  **          6       25       38.       -15.         1.        0.
  7     91        56.          42.        2.        0.  **          8       91      -43.       -33.         1.        0.
  9    120       -10.         -13.        0.        0.  **         10       91       44.        59.         1.       -1.
 11     91       -56.         -56.        1.       -1.  **         12       25      -38.        17.         0.        0.
 13    120       -35.           0.        0.        0.  **         14       91      -54.       -55.         0.       -1.
 15     91        49.          45.        0.       -2.  **         16      120       40.        93.         1.       26.
 17    120       -38.           7.        0.        0.  **         18       91       57.       229.         4.       17.
 19     91       -35.         -16.        0.        0.  **         20       11       30.        87.         1.        1.
 21     91        50.           0.        0.        0.  **         22       91      -53.       -58.         0.        0.
 23     25       -37.         -11.        0.        0.  **         24       25      -36.        10.         0.        0.
 25     91       -56.          -2.        0.        0.  **         26       91       42.        29.         0.        0.
 27    120        28.          81.        0.        0.  **         28       91      -45.       -79.         0.        0.
 29     91        56.         116.        0.        1.  **         30      120      -40.       -52.         0.        0.
 31    120        40.          35.        0.        0.  **         32       91       55.        42.         0.        0.
 33     91       -48.         -30.        0.        0.  **         34      120      -33.       -54.         0.        0.
 35     91        39.         -13.        0.        0.  **         36       91      -57.      -158.         0.        1.
 37     91        34.         -14.        0.        0.  **         38       11      -31.       -35.         0.        0.
 39     91       -51.         -35.        0.        0.  **         40       91       52.        70.         0.        0.
 41     25        38.         -10.        0.        0.  **         42       25       33.        -7.         0.        0.
 43     91        57.         -10.        0.        0.  **         44       91      -41.       -11.         0.        0.
 45    120       -39.         -97.        0.        0.  **         46       91       46.        97.         0.        0.
 47     91       -55.        -125.        0.        0.  **         48      120       38.        51.         0.        0.
 49    120       -35.         -13.        0.        0.  **         50       91      -55.       -54.         0.        0.

TUNE SHIFT WITH BETATRON AMPLITUDE X0:   DNUEX =       2.95851E+01 * X0**2/BETAX0
--------------------------------------------------------------------------------------REAL-TIME SO FAR =         18. SEC


ENERGY VARIATION (IT: # OF ITERATIONS USED TO GET A PERIODIC ETA-FUNCTION WITH SEXTUPOLES)                     KW(5)= 1
    DP/P          BETAX*       BETAY*       ETAX*        ETAY*      DETA/ETAX      IT

   0.00000       1.61095      7.15119      0.79040      0.00000     0.000E+00       0
  -0.50000       1.58780      6.67527      0.78970      0.00000     0.979E-09       2
  -1.00000       1.56522      6.21831      0.78908      0.00000     0.628E-08       2
  -1.50000       1.54358      5.78176      0.78852      0.00000     0.170E-07       2
  -2.00000       1.52322      5.36601      0.78801      0.00000     0.320E-07       2
  -2.50000       1.50453      4.97043      0.78755      0.00000     0.494E-07       2
   0.50000       1.63433      7.64344      0.79120      0.00000    -0.733E-09       1
   1.00000       1.65759      8.14823      0.79209      0.00000    -0.208E-08       1
   1.50000       1.68037      8.66063      0.79310      0.00000    -0.102E-07       1
   2.00000       1.70231      9.17461      0.79423      0.00000    -0.357E-07       1
   2.50000       1.72304      9.68328      0.79549      0.00000     0.496E-11       1
```

```
           BETA(DP/P)/BETA(DP/P=0) AT THE REF.POINT : (J=1)   22 SEXTUPOLES PER SUPERPERIOD   *** PROGRAM P A T R I C I A 85.5 ***
        2.000 +
              I
              I
              I
              I
        1.800 +
              I
              I
              I
              I
        1.600 +
              I
              I
              I
              I
        1.400 +
              I                                                                                                                        Y
              I
              I                                                                                                            Y
              I
        1.200 +                                                                                                Y
              I
              I                                                                                    Y
              I                                                                        Y                                               X
              I                                                                                    X           X           X
        1.000 +E           E           E           E           E           E           E           E           E           E           E
              I            X           X           X
              IX                                               Y
              I                                    Y
              I
        0.800 +                        Y
              I            Y
              I
              IY
              I
        0.600 +
              I
              I
              I
              I
        0.400 +
              I
              I
              I
              I
        0.200 +
              I
              I
              I
              I
        0.000 +
              ---------------------------------------------------------------------------------------------------------------------------
               I                       I                       I                       I                       I                       I
            -2.500                  -1.500                  -0.500                   0.500                   1.500 DP/P IN PERCENT 2.500

BETX0      1.5045      1.5232      1.5436      1.5652      1.5878      1.6110      1.6343      1.6576      1.6804      1.7023      1.7230
BETY0      4.9704      5.3660      5.7818      6.2183      6.6753      7.1512      7.6434      8.1482      8.6606      9.1746      9.6833
ETAX0      0.7876      0.7880      0.7885      0.7891      0.7897      0.7904      0.7912      0.7921      0.7931      0.7942      0.7955
ETAY0      0.0000      0.0000      0.0000      0.0000      0.0000      0.0000      0.0000      0.0000      0.0000      0.0000      0.0000
```

```
        NONINTEGRAL PART OF THE TUNE VS. MOMENTUM          22 MULTIPOLES PER SUPERPERIOD    *** PROGRAM P A T R I C I A 85.5  ***
       1.000 +
             I
             I
             I
             I
       0.900 +
             I
             I
             I
             I
       0.800 +
             I
             I
             I
             I
       0.700 +
             I
             I
             I
             I
       0.600 +
             I
             I
             I
             I
       0.500 +
             I
             I
             I
             I
       0.400 +
             I
             I
             I
             I
       0.300 +
             I
             I
             IX         X         X         X         X         X         X         X         X         X         X
             I
       0.200 +
             I                              Y         Y         Y         Y         Y         Y         Y         Y
             IY         Y         Y
             I
             I
       0.100 +
             I
             I
             I
             I
       0.000 +
             ----------------------------------------------------------------------------------------------------------
              I                   I                   I                   I                   I                   I
            -2.500              -1.500              -0.500               0.500               1.500 DP/P IN PERCENT 2.500

 NUEX      0.2456    0.2456    0.2456    0.2456    0.2456    0.2455    0.2453    0.2450    0.2446    0.2441    0.2434
 NUEY      0.1662    0.1684    0.1698    0.1706    0.1710    0.1711    0.1710    0.1708    0.1707    0.1707    0.1708
----------------------------------------------------------------------------------------------------REAL-TIME SO FAR =        36. SEC
----------------------------------------------------------------------------------------------------REAL-TIME SO FAR =        36. SEC
```

```
BETA VARIATION WITH MOMENTUM : (DBETA/BETA)/(DP/P) VS. PHASE                       *** PROGRAM P A T R I C I A 85.5  ***

 150.000 +
         I
         I
         I
         I
 120.000 +
         I
         I
         I
         I
  90.000 +
         I
         I
         I
         I
  60.000 +
         I
         I
         I
         I
  30.000 +
         I
         I        Y Y
         I     YYYY YY                                     YYY
         I    YY      YY   X X XX   YYYY Y       XXX XXX YY    Y   X X XXXX               X   X XX            XX
   0.000 +XX YXXX       YY      XYYYY      YYXXX     YYYY        YX        X X        XXXX      X X        X
         I  Y       XXXX  YY    YY   XXX  X  YY   YYYYY    X  XX  Y YY YY      XXXXXX               XXX XX
         IY                YYY Y               YYY
         I
         I
 -30.000 +
         I
         I
         I
         I
 -60.000 +
         I
         I
         I
         I
 -90.000 +
         I
         I
         I
         I
-120.000 +
         I
         I
         I
         I
-150.000 +
         -----------------------------------------------------------------------------------------------------------
          I                    I                    I                    I                    I                    I
         0.000                0.538                1.076                1.613                2.151  PHASE/(2*PI) 2.689
```

```
ETA-VARIATION WITH MOMENTUM (LINEAR TERM IN DP/P)VS PHASE                    *** PROGRAM P A T R I C I A 85.5 ***

                                   *** MOMENTUM COMPACTION FACTOR: AC =     5.40384E-02 +     1.99591E-02*(DP/P) ***
 2.226 +
       I                                          X
       I                                         XX
       I                                         X
       I
 1.781 +                                          X
       I
       I                                         X
       I
       I
 1.335 +
       I                                           X
       I
       I                                       X
       I     XX
 0.890 +     XX
       I                                      X      X                               XX
       I    X  X                                      X                              X         X
       I                                              X                              X  XX
       I                                     X         X                                  XXX    XX
 0.445 +                                   XX                                                     X
       I                                                                            X
       IXX                                X                                                         X
       I
       I           X                                                               X
 0.000 +            X                                                             X
       I            X                                       X                    X
       I             X                 X
       I             XX                                                         X                       X
       I                                                                                                 X
-0.445 +                                                                                                 X
       I                                                                     X
       I                                                                                                  X
       I                                                                                                  X
       I                X      X                                  XX
-0.890 +                      X X     X                            XX                                             X
       I                         X                             XX          X                                     X
       I                            X X                               X
       I                    X         X
       I                             XX
-1.335 +                                                                 X                                 X
       I                                                                   X
       I                                                                  X                                   X
       I                  X                                               X
       I                  X
-1.781 +
       I
       I
       I                                                                                                    X
       I                                                                                                    X
-2.226 +                                                                                                    X
       -------------------------------------------------------------------------------------------------------------
       I                     I                     I                     I                     I                     I
       0.000                0.538                 1.076                 1.613                 2.151  PHASE/(2*PI)   2.689
--------------------------------------------------------------------------------------------REAL-TIME SO FAR =        67. SEC
--------------------------------------------------------------------------------------------REAL-TIME SO FAR =        67. SEC
--------------------------------------------------------------------------------------------REAL-TIME SO FAR =        67. SEC
```

```
                    *** PROGRAM P A T R I C I A 85.5  ***            31-JUL-87     10:47:52

3 GEV BOOSTER
------------------------------------------------------------------------------------------------

               **** D Y N A M I C - A P E R T U R E  (at J =   1) ****
AMPLITUDES IN SIGMA. ( 1000 TURNS ; DP/P=   0.00000 % ; SIGMAX=   0.87721 MM   SIGMAY=   1.30688 MM )
 15.303 +
        I
        I
        I*  *  *  *  *  *  *  *  *  *  *  *  *  *  *  *  *  *  *  *  *  *  *  *  *  *  *  *  *
        I
 13.773 +
        I
        I*  *  *  *  *  *  *  *  *  *  *  *  *  *  *  *  *  *  *  *  *  *  *  *  *  *  *  *  *
        I
        I
 12.242 +*  *  *  *  *  *  *  *  *  *  *  *  *  *  *  *  *  *  *  *  *  *  *  *  *  *  *  *  *
        I
        I
        I
        I*  *  *  *  *  *  *  *  *  *  *  *  *  *  *  *  *  *  *  *  *  *  *  *  *  *  *  *  *
 10.712 +
        I
        I
        I*  *  *  *  *  *  *  *  *  *  *  *  *  *  *  *  *  *  *  *  *  *  *  *  *  *  *  *  *
        I
  9.182 +
        I
        I*  *  *  *  *  *  *  *  *  *  *  *  *  *  *  *  *  *  *  *  *  *  *  *  *  *  *  *  *
        I
        I
  7.652 +
        I*  *  *  *  *  *  *  *  *  *  *  *  *  *  *  *  *  *  *  *  *  *  *  *  *  *  *  *  *
        I
        I
        I
  6.121 +*  *  *  *  *  *  *  *  *  *  *  *  *  *  *  *  *  *  *  *  *  *  *  *  *  *  *  *
        I
        I
        I
        I   *  *  *  *  *  *  *  *  *  *  *  *  *  *  *  *  *  *  *  *  *  *  *  *  *  *
  4.591 +
        I
        I
        I*  *  *  *  *  *  *  *  *  *  *  *  *  *  *  *  *  *  *  *  *  *  *  *  *  *  *
        I
  3.061 +
        I
        I*  *  *  *  *  *  *  *  *  *  *  *  *  *  *  *  *  *  *  *  *  *  *  *  *  *
        I
        I
  1.530 +
        I*  *  *  *  *  *  *  *  *  *  *  *  *  *  *  *  *  *  *  *  *  *  *  *  *  *  *  *  *
        I
        I
        I
  0.000 +*  *  *  *  *  *  *  *  *  *  *  *  *  *  *  **  *  *  *  *  *  *  *  *  *  *  *  *  *
        ------------------------------------------------------------------------------------------
         I                 I                 I                 I                 I                 I
      -17.100           -10.260           -3.420             3.420            10.260            17.100
```

```
                                   *** PROGRAM P A T R I C I A 85.5  ***                     31-JUL-87     11:24:40

3 GEV BOOSTER
_____________________________________________________________________________________________________________________

                   **** D Y N A M I C - A P E R T U R E  (at J =   1) ****
AMPLITUDES IN  MM . ( 1000 TURNS ; DP/P=   0.00000 % ; SIGMAX=   0.87721 MM   SIGMAY=   1.30688 MM )
19.999 +
       I
       I
       I*   *   *   *   *  *   *   *   *   *   *   *   *   *  *   *   *   *   *   *   *   *   *  *   *   *   *   *   *
       I
17.999 +
       I
       I*   *   *   *   *  *   *   *   *   *   *   *   *   *  *   *   *   *   *   *   *   *   *  *   *   *   *   *   *
       I
       I
15.999 +*   *   *   *   *  *   *   *   *   *   *   *   *   *  *   *   *   *   *   *   *   *   *  *   *   *   *   *   *
       I
       I
       I
       I*   *   *   *   *  *   *   *   *   *   *   *   *   *  *   *   *   *   *   *   *   *   *  *   *   *   *   *   *
13.999 +
       I
       I
       I*   *   *   *   *  *   *   *   *   *   *   *   *   *  *   *   *   *   *   *   *   *   *  *   *   *   *   *   *
       I
12.000 +
       I
       I*   *   *   *   *  *   *   *   *   *   *   *   *   *  *   *   *   *   *   *   *   *   *  *   *   *   *   *   *
       I
       I
10.000 +
       I*   *   *   *   *  *   *   *   *   *   *   *   *   *  *   *   *   *   *   *   *   *   *  *   *   *   *   *   *
       I
       I
       I
 8.000 +*   *   *   *   *  *   *   *   *   *   *   *   *   *  *   *   *   *   *   *   *   *   *  *   *   *   *   *
       I
       I
       I
       I    *   *   *   *  *   *   *   *   *   *   *   *   *  *   *   *   *   *   *   *   *   *  *   *   *   *
 6.000 +
       I
       I
       I*   *   *   *   *  *   *   *   *   *   *   *   *   *  *   *   *   *   *   *   *   *   *  *   *   *   *
       I
 4.000 +
       I
       I*   *   *   *   *  *   *   *   *   *   *   *   *   *  *   *   *   *   *   *   *   *   *  *   *   *
       I
       I
 2.000 +
       I*   *   *   *   *  *   *   *   *   *   *   *   *   *  *   *   *   *   *   *   *   *   *  *   *   *   *   *   *
       I
       I
       I
 0.000 +*   *   *   *   *  *   *   *   *   *   *   *   *   *  **  *   *   *   *   *   *   *   *  *   *   *   *   *   *
       ---------------------------------------------------------------------------------------------------------------
        I                     I                      I                     I                     I                      I
     -15.000                -9.000                -3.000                 3.000                 9.000                  15.000
_____________________________________________________________________________________________REAL-TIME SO FAR =      2242. SEC
```