## E. Injection System

### 1. Requirements

The injection system transports the electron and positron beams from the two-mile linear accelerator and switches them onto stable orbits within the vacuum chamber of the PEP ring. The SLAC beams have the following parameters:

| | |
|---|---|
| Energies | 4 to 15 GeV |
| Momentum width | ± 0.5% |
| Emittance, positrons | 0.2 $\pi$ (15 GeV/E) mm-mrad |
| Emittance, electrons | 0.02 $\pi$ (15 GeV/E) mm-mrad |
| Pulse length | 1 ns |
| Particles per pulse | $1.3 \times 10^8$ positrons, and |
| | $1.3 \times 10^9$ electrons |
| Repetition rate | up to 360 pps |

### 2. Transport System

The transport system has been designed to transmit a momentum width of ± 0.8% with a resolution of at least ± 0.3%. The magnet apertures are determined largely by the momentum passband and resolution requirements. The monoenergetic emittance of the SLAC linac is easily transmitted and is only of secondary importance in determining the required apertures in the transport system.

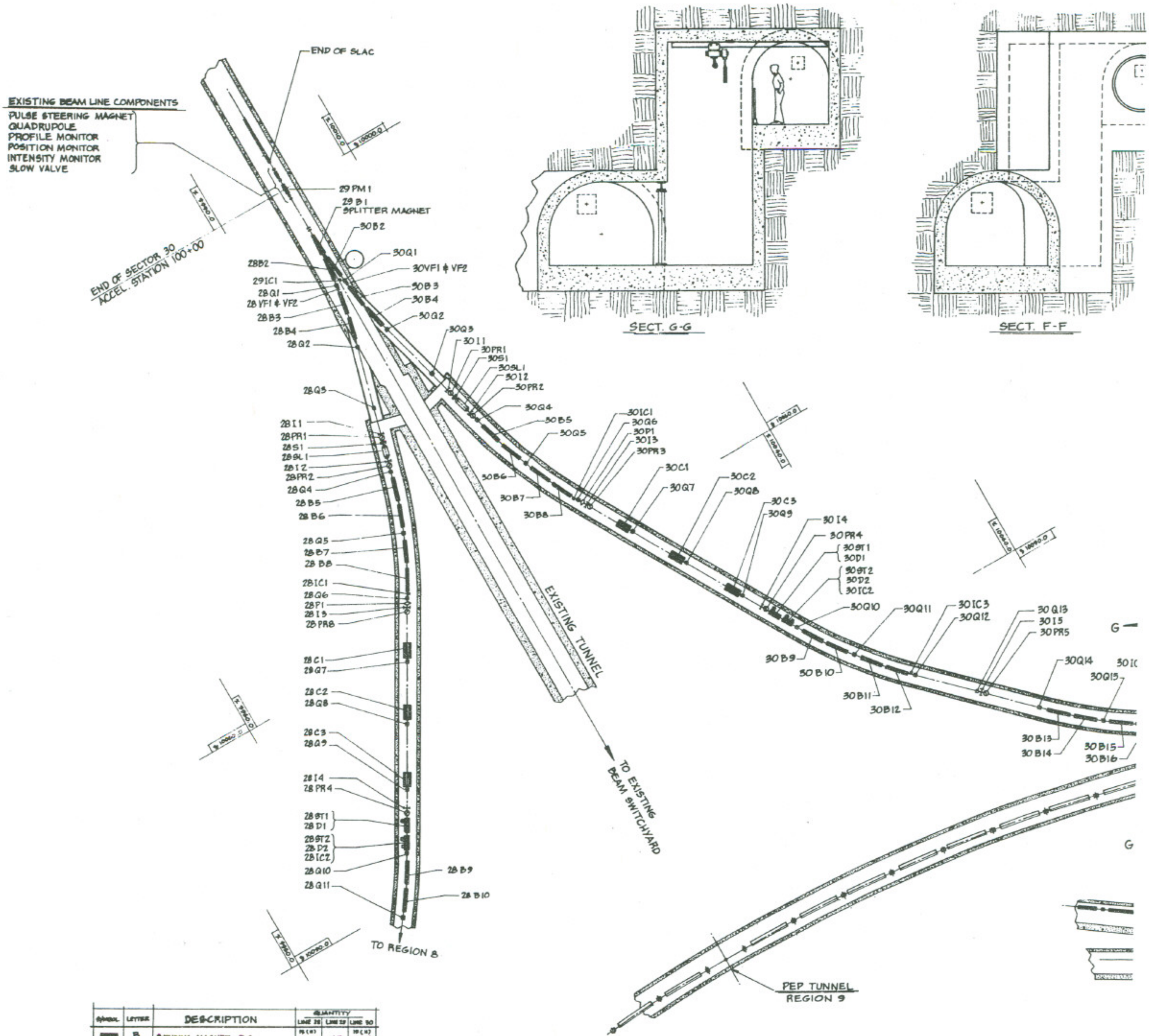
For reasons of cost coupled with the relatively modest momentum resolution demanded of the system, a simple periodic FODO array of identical quadrupoles with interspersed bending magnets is selected as the design basis of the system. The horizontal aperture requirements are uniquely determined by the spacing $\ell$ between quadrupoles, the total angle of the bend, and the required momentum pass-band. For the vertical apertures the transmitted monoenergetic emittance of the beam is determining. The required apertures are ± 25 mm for the "good" field region of the quadrupoles and 25 mm for the total bending-magnet gap.

For the periodic FODO quadrupole array, the phase shift per unit cell (length, $2\ell$) is chosen to be $90^{\circ}$. It follows, then, that the monoenergetic matrix transformation between any two positions separated by a distance of $4\ell$ is $-I$ (the negative unit matrix). Because of this, each 360-degree-phase-shift segment of the system will be achromatic if, for every $\Delta\alpha$ of bend angle inserted at any position s there is an equal $\Delta\alpha$ of bend inserted at a position $(s + 4\ell)$.

The proposed design is illustrated in Fig. 45. The total system consists basically of three $360^{\circ}$ achromatic segments,* the first two bending in an approximately horizontal plane and the last in the vertical plane. The plane of the nearly horizontal segments is rolled a few degrees about the initial linac beam axis so as to carry the beams down to the lower elevation of the storage ring.

The distribution of bending magnets has been selected for practical reasons consistent with the above rule for achromaticity. In the first two segments, the bending magnets are distributed as shown because of two dominant considerations: first, that there are "missing" magnets to simplify transporting the beam through existing SLAC concrete walls, and, second, that the first and second achromatic segments are placed in mirror symmetry so as to provide five quadrupoles (28Q6 through 28Q10) in the achromatic region between the two segments to adjust the monoenergetic beam phase ellipses to match the various possible PEP injection configurations. In addition, two appropriate quadrupoles (e.g., 28Q12 and 28Q16) in the second $360^{\circ}$ segment, separated by a minus unity transformation, are varied in the opposing sense so as to vary $\eta' = dx'/d(\Delta p/p)$ at the injection point

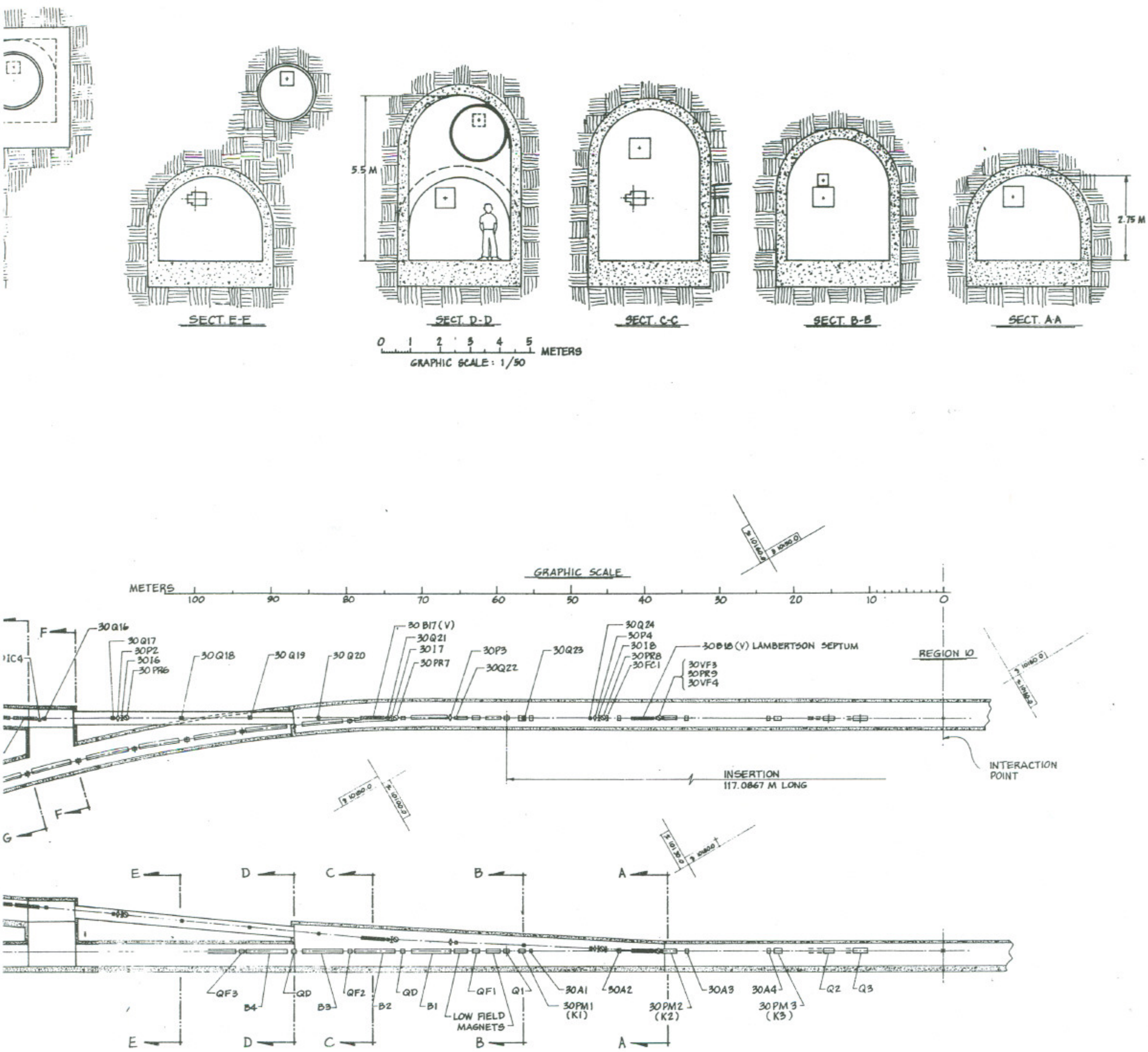
*In this section the term $360^{\circ}$ will refer to phase shift.




| SYMBOL | LETTER | DESCRIPTION | QUANTITY LINE 28 | LINE 29 | LINE 30 |
|---|---|---|---|---|---|
| | B | BENDING MAGNET, D.C. | 15(H) 2(V) | 1(H) | 10(H) 2(V) |
| | Q | QUAD MAGNET, D.C. | 24 | 0 | 24 |
| | PM | PULSE MAGNET | 5(H) | 1(V) | 5(H) |
| | A | "BUMP" STEERING MAGNET | 4(H) | 0 | 4(H) |
| | I | BEAM CURRENT INTENSITY MONITOR | 5 | 0 | 5 |
| | PR | BEAM PROFILE MONITOR (PROFILE SCREEN) | 10 | 0 | 10 |
| | P | BEAM POSITION MONITOR | 4 | 0 | 4 |
| | SL | ENERGY DEFINING SLIT | 1 | 0 | 1 |
| | S | BEAM ENERGY SPECTRUM INDICATOR | 1 | 0 | 1 |
| | ST | BEAM STOPPER | 2 | 0 | 2 |
| | DM | DISASTER MONITOR | 2 | 0 | 2 |
| | IC | IONIZATION CHAMBER | 5 | 1 | 5 |
| | VF | VACUUM ISOLATION FOIL | 4 | 0 | 4 |
| | FC | FARADAY CUP | 1 | 0 | 1 |
| | C | COLLIMATOR | 3 | 0 | 3 |
| | ES | ELECTROSTATIC SEPARATION PLATE | 3 | 0 | 3 |

Fig. 45--Injection bean

4 4 U 2 9 6 3




m lines from SLAC to PEP.

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without disturbing the monoenergetic phase-space configurations.

The last 360° achromatic segment bends the beam vertically a total of 88 milliradians and deposits it at the ring injection position via a Lambertson iron-septum magnet.

3. Pulsed Inflection System

The injection process whereby electrons or positrons from the linac are trapped in the PEP storage ring has two steps, as illustrated in Fig. 46 and 47: (1) a launch into a stable orbit in the ring, having large-amplitude betatron oscillation, followed by (2) a slow damping of that oscillation down into a small-amplitude equilibrium distribution.

The entering particles are deflected horizontally by a pulsed "kicker" magnet (Kicker Magnet 3) onto an orbit in which they can safely circulate within the vacuum chamber with a radial collective betatron oscillation of 2- or 3-cm amplitude, depending on the lattice configuration in use. To compensate the effect of this kicker magnet on the beam already stored in the ring, it is made part of a triad of pulsed magnets (Kickers 1, 2, and 3) whose function is to distort, or "bump," the local closed orbit at the time of injection as illustrated in Fig. 46. The amplitude of the bump required is the sum of the width of the injected envelope (including dispersion effects), the septum width, and a small allowance for clearance, the sum typically running 1 to 2 cm. In this system, the septum separating the external path of the entering beam from the internal orbits is the thin conductor which terminates the central field of Kicker Magnet 2.

In addition to the triad of pulsed kicker magnets, which produce the fast bump, a quartet of dc magnets is arranged in the injection area to produce a dc bump of variable amplitude and slope at the point of injection. This variable bump helps match the beam optics of the transport line to that of the wide range

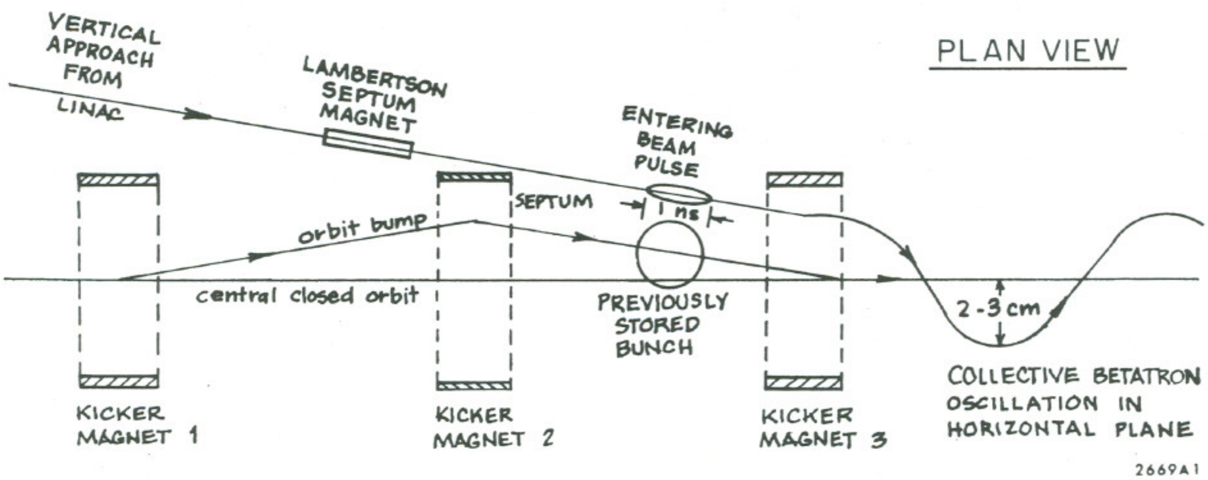


Fig. 46--PEP injection system (schematic).

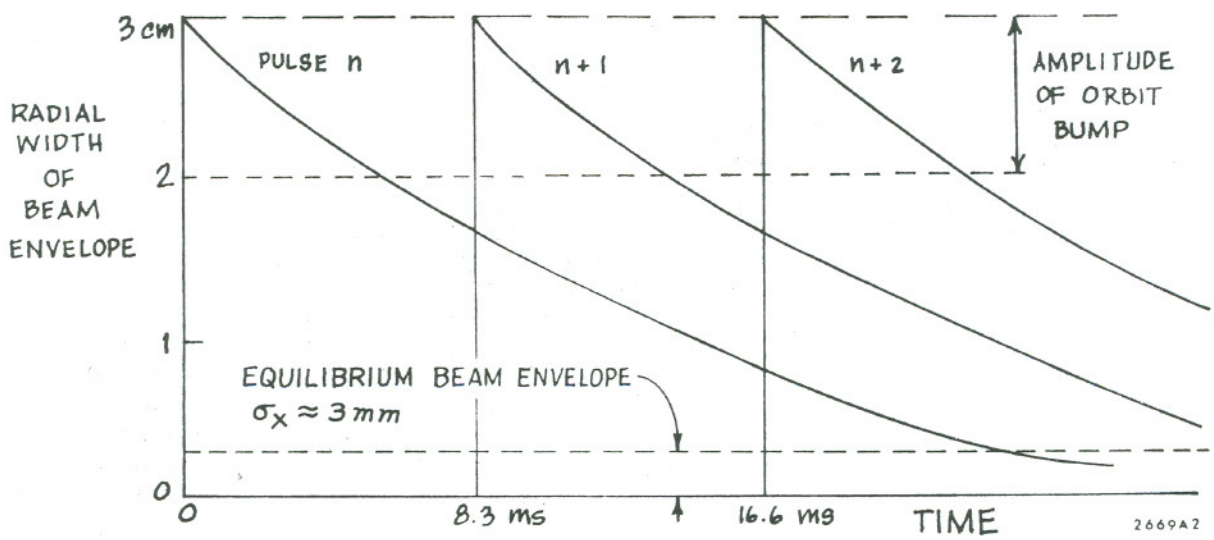


Fig. 47--Radiation damping of beam envelope after injection of several beam pulses.

of lattice configurations which can be used in the PEP ring. The beam exits the transport line through a foil window and enters the ring vacuum through another foil window that is on the inner radius of the ring in order to protect it from the intense synchrotron radiation. In the vertical plane, the beam is centered and phase space matched.

4. Injection Rates

While the beam circulates, the synchrotron-radiation process continuously damps the beam dimensions and also the energy spread toward an equilibrium distribution determined by quantum fluctuations. This radiation process allows each injected pulse of particles eventually to be deposited in a volume of phase space already occupied by previously stored bunches and thus avoids the limitation of constant phase-space density (Liouville's Theorem) common in proton machines. Also, it is a "forgiving and forgetting" process in the sense that deliberate or accidental variations in the injection procedure do not affect the final equilibrium beam distribution.

The loading time of the storage ring is short but not negligible. To load 92 mA of electrons and positrons into the ring at 15 GeV from the linear accelerator operating at 360 pps takes about 5 minutes. This maximum repetition rate of 360 pps is possible only at energies greater than 12.5 GeV, where the damping time in the storage ring is less than 8.33 milliseconds, the time needed to load three successive linac pulses into the three active RF buckets in a beam. At lower energies, the damping times in the normal lattice would increase as $E^{-3}$. However, the wiggler system serves to shorten the damping times so that the effective energy dependence is approximately $E^{-2}$. The required current in the ring varies as E, so that the overall filling time below 12.5 GeV varies approximately as $E^{-1}$, as shown in Fig. 48. Since the usable SLAC repetition rate is

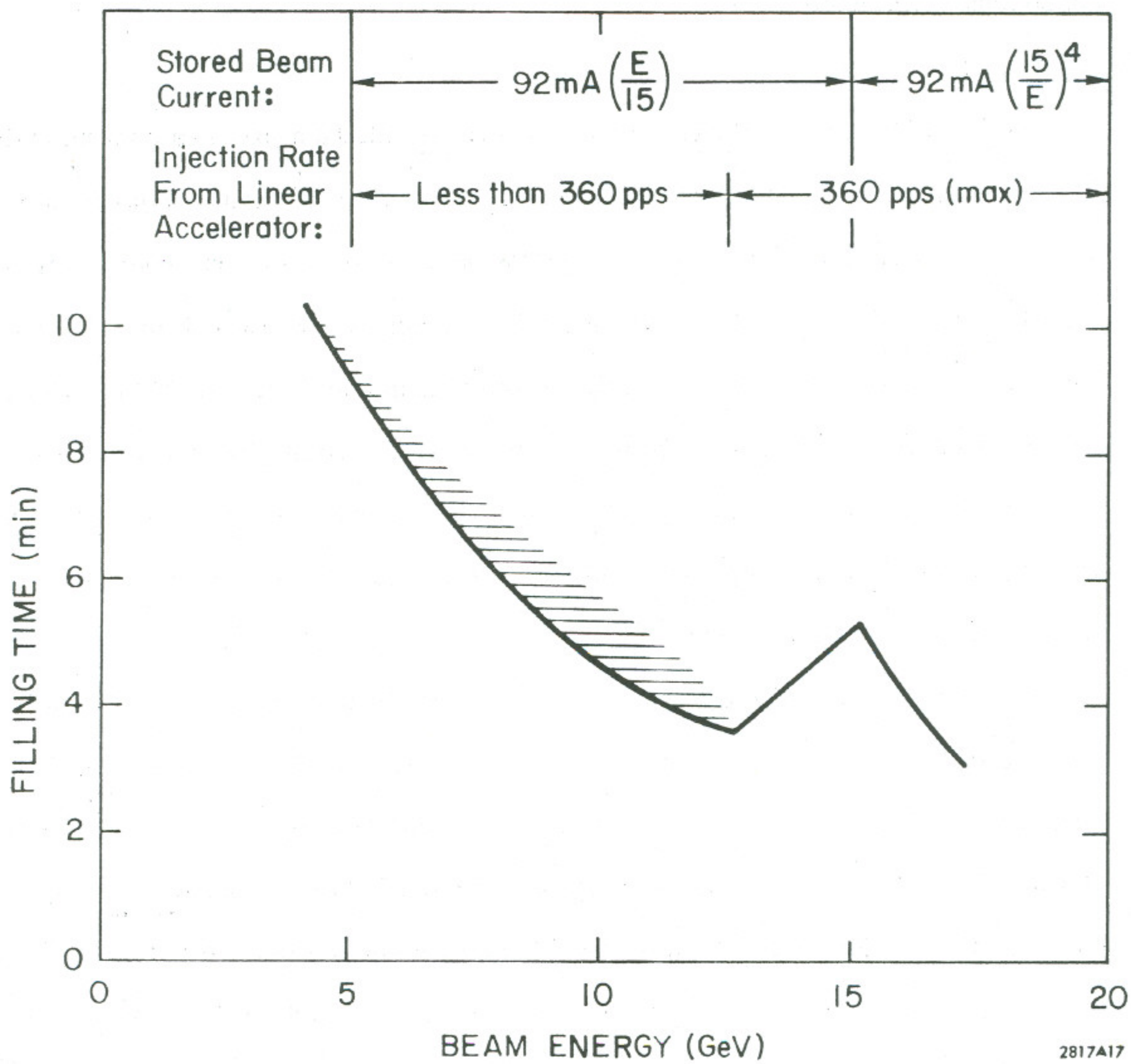


Fig. 48--Filling time into PEP.

quantized, the actual curve has small jogs where the ratio of beam-damping time to SLAC-interval times becomes an integral number; the dashed area on the curve of filling time represents this irregularity. Above 15 GeV, the filling time drops because the required current falls as $E^{-4}$. With the wiggler system, the filling time requirements below 15 GeV are reduced significantly from those in systems in which beam size is controlled by varying the betatron tunes and the dispersion function.

A special new electron gun, installed on the two-mile accelerator to provide the high peak currents and the short pulses necessary for injection into the SPEAR II storage ring, has been in use since October of 1974. It is now providing peak positron currents at the end of the accelerator in excess of 20 mA. This performance is adequate for the proposed PEP requirements, so that a further major gun development is not necessary. The filling time curve of Fig. 48 is based on the assumption that only 50% of the 20-mA positron current from the linac is transmitted and trapped in the PEP ring.

Precise timing and energy definition are required for successful injection. Each injected pulse contains $10^8$ positrons or $10^9$ electrons, is about 1 ns in length (consisting of four s-band pulses), and has ± 0.5% energy spread. These dimensions just fit within a typical RF bucket in the PEP ring. Furthermore, each injected pulse must be placed in a specific RF bucket, one of three in use (out of a total of 2592 in the ring). This requires precise timing, but the means of doing it are already in use on SPEAR.

5. Major Components in the Injection System

A description of the major components in the transport line and injection system and their principal characteristics at 15 GeV is as follows (see also Fig. 45):

(1) Pulsed Switching Magnet (29PM1)

| | |
|---|---|
| Maximum Field | 3.3 kG |
| Effective Length | 0.96 m |
| Bend Angle (15 GeV) | 6.3 mr |
| Clear Aperture | ± 12.5 mm |
| Wave Form | Single 600-Hz sinusoid |
| Repetition Rate | 360 Hz |
| Peak Voltage and Current | 3.8 kV, 420 A |
| Average Power | 3 kW |
| Weight | 725 kg |
| Number Required | 1 |

Comment: The design will probably be that of the SLAC switch magnet PM30 with the aperture increased by 25% to accommodate a ceramic vacuum chamber.

(2) Splitter Iron-Septum Magnet (29B1)

| | |
|---|---|
| Maximum Field | 10.9 kG |
| Effective Length | 3.0 m |
| Beam Angle (15 GeV) | 65 mr ($3.75^{\circ}$) |
| Gap Height | 30 mm |
| Clear Aperture | ± 12.5 m (vert.), ± 115 mm (horiz.) |
| Ampere-turns | 35,000 A-t, dc |
| Power | 22 kW |
| Weight | 9000 kg |
| Number Required | 1 |

(3) Horizontal Bend Magnets (28B2 to 28B16, 30B2 to 30B16)

| | |
|---|---|
| Maximum Field | 12.6 kG |
| Effective Length | 2.6 m |
| Bend Angle (15 GeV) | 65 mr ($3.75^{\circ}$) |
| Gap Height | 30 mm |
| Clear Aperture | ± 12.5 mm (vert.), ± 25 mm (horiz.) |
| Ampere-turns | 32,000 A-t, dc |
| Power | 12 kW |
| Weight | 2700 kg |
| Number Required | 30 |

Comment: Each magnet will have auxiliary windings for providing up to 0.65 mr horizontal steering.

(4) Quadrupoles (28Q1 to 28Q23, 30Q1 to 30Q23)

| | |
|---|---|
| Maximum Gradient | 3.0 kG/cm |
| Effective Length | 0.4 m |
| Inscribed Radius | 30 mm |
| Clear Aperture | 25.0 mm radius |
| Ampere-turns/pole | 12,000 A-t, dc |
| Power | 7.9 kW, max. |
| Weight | 225 kg |
| Number Required | 46 |

Comment: Each quadrupole will have auxiliary windings for providing up to 0.4 mr horizontal and vertical steering.

(5) Vertical Bend Magnets (28B17, 30B17)

| | |
|---|---|
| Maximum Field | 7.3 kG |
| Effective Length | 3.0 m |
| Bend Angle | 44 mr ($2.5^{o}$) |
| Gap Height | 45 mm |
| Clear Aperture | ± 20 mm (horiz.), ± 35 mm (vert.) |
| Ampere-turns | 28,000 A-t, dc |
| Power | 10 kW |
| Weight | 2250 kg |
| Number Required | 2 |

(6) Injection Iron-Septum Magnets (28B18, 30B18)

| | |
|---|---|
| Maximum Field | 7.3 kG |
| Effective Length | 3.0 m |
| Bend Angle (15 GeV) | 44 mr ($2.5^{o}$) |
| Gap Height | 35 mm |
| Clear Aperture | ± 12.5 mm (horiz.), ± 25 mm (vert.) |
| Ampere-turns | 21,500 A-t, dc |
| Power | 8.2 kW |
| Weight | 2250 kg |
| Number Required | 2 |

(7) Pulsed Kicker Magnets (28PM1 to 28PM3, 30PM1 to 30PM3)

| | |
|---|---|
| Maximum Field | ~ 0.6 kG |
| Effective Length | 1.0 m (PM1 and 3), 2.0 m (PM2) |
| Clear Aperture, Vert. | ~ ± 40 mm |
| Clear Aperture, Horiz. | ~ ± 40 to ± 80 mm |
| Wave Form | Half-sinusoid, damped, 3 $\mu$s long |
| Peak Voltage | 12 to 19 kV |
| Peak Current | 10 to 15 kA |
| Repetition Rate | 360 Hz |
| Number Required | 6 |

(8) D. C. Bump Magnets (28A1 to 28A4, 30A1 to 30A4)

| | |
|---|---|
| Maximum Field | 4.7 kG |
| Effective Length | 0.5 m |
| Gap Height | 140 mm |
| Clear Aperture, Vert. | ± 25 to ± 40 mm |
| Clear Aperture, Horiz. | ± 50 to ± 80 mm |
| Ampere-turns | 23 to 50 kA-t |
| Maximum Power | 2 to 5 kW |
| Weight | ~ 225 kg |
| Number Required | 8 |

(9) Instrumentation

The injection line instrumentation components to measure and/or to define the beam intensity, emittance, size, position and energy spectrum are indicated by symbols in Fig. 45. In general, the design of this equipment follows that already being used in the various beam transport lines at the SLAC-SPEAR complex. A listing of the types of instruments and the number required of each component is as follows:

| Component | Number Required |
|---|---|
| Beam Intensity Monitor | 17 |
| Beam Profile Monitor | 21 |
| Beam Position Monitor | 9 |
| Energy Defining Slit | 2 |
| Energy Spectrum Monitor | 2 |
| Ionization Monitor | 11 |
| Beam Stopper | 4 |
| Emittance Collimators | 6 |

(10) Vacuum

The vacuum requirements for the injection lines are modest. A pressure of $10^{-3}$ Torr is adequate, so that relatively crude vacuum hardware and pumping will be enough. This coarse vacuum in the injection line will be isolated from the high vacua in the SLAC linac and the PEP ring by pairs of thin foils or cold-trap sections.

## F. Data System for Monitoring and Control

### 1. Introduction

The PEP storage ring system physically covers too wide an area for a single data-collection point to be practical. We will, therefore, collect data at a number of places. It will be edited and compressed as much as possible and then transmitted to the control room, located near one of the injection points, creating a short path for direct transmission of fast monitoring signals from the injection lines.

Data from magnet interlocks, vacuum pressure gauges, beam monitors, and small magnet-trim power supplies will be gathered at centers in Regions 2, 4, 6, 8, 10, and 12. In Regions 4, 8, and 12, the data center will also be adjacent to the RF system reducing the amount of control cabling. The bend-magnet power supplies are also in these same areas. This consolidation not only makes for efficient utilization of installed equipment, but also simplifies providing of the required utilities such as LCW and ac power. The surface buildings at Regions 8 and 10 will also house the power supplies and controls for the injection beam transport lines.

Signals generated within the bending arcs will, for the most part, be wired only to instrumentation racks in the nearest data center to further reduce the amount of cabling. Interlock signals will be summarized there and wired directly to the equipment they must control. The remaining signals will be edited by a small local computer and sent by serial link to the control room. The computer in the data-collection area will have provision for graphic displays, eliminating the need for extensive alarm and annunciator panels.

### 2. Control System

The control system will depend heavily upon several small computers. Fourteen of these will be connected by links to the Central Control Computer. These small computers will be "real time" units, while the larger Central Control Computer will interface with the outside world. A link to the SLAC IBM Triplex computer system can supplement this computer. At each small computer a small control console will aid in checkout and maintenance of the equipment associated with that computer.

3. Timing

Much of the instrumentation will require timing signals at the circulation frequency of the ring for gating of beam monitors and feedback systems, for injection, for displays in the control room, and for experimenters. The timing system will divide the 353 MHz radio frequency to the 136 kHz revolution frequency and distribute a reference signal to each data area. Timing repeaters will then provide separate channels with individual delays for each instrument.

4. Magnet and Guidance Controls

The controllers for magnet power supplies will be standardized as much as possible, and will include a digital-to-analog converter attached to each power supply regulator. All of the converters are to be of the same design and the magnet power supply regulators will be designed to accept signals in the same voltage range, e.g., 0 - 10 V. Each power supply will have an individual controller. The ganging of controls for magnets which have identical currents, but which are physically too far apart to be in series, will be accomplished in the computer system software.

The high-voltage supplies for the electrostatic guidance plates will be remotely controlled, the controllers being similar to those of the magnet power supplies.

5. RF System Control

The RF system will be largely self-contained; for example, it will have the internal logic for phasing on command. The control system will provide for operator's instructions for phasing and control of RF voltage amplitude, and it will monitor the general health of the RF system components.

6. Interlocks and Miscellaneous

All interlocks will be hard-wired to cross-connect racks located at each data-gathering center using relay logic wherever possible. If semi-conductor logic proves to be preferable, it will be designed to be at least twofold redundant and self-checking. The relay logic will be redundant with checking capabilities incorporated where personnel protection is involved.

Analog and status signals for vacuum gauges, pumps, vacuum-valve position, trim-magnet current and thermocouple signals will be read into the computer system at each data-gathering location and will also be available at each data-gathering point as an aid in maintenance of equipment when the local computer is down.

All the vacuum valves will be controlled by a hard-wire system. The fast valves will be controlled via vacuum gauges. The permissive signal to open the vacuum valves will be under the control of the control room operators via a hard-wire system.

For personnel protection, a system of gates and monitors to control access to the arcs and to the interaction areas will prevent the injection or circulation of beam if any area can be occupied.

7. Beam Monitoring

The synchrotron light monitor consists of optics and sensors to generate a TV image of the beam and provide beam-profile and bunch-length information. The light emitted from the two counter-rotating beams will be collected separately and photodiodes will be used to measure the current in each beam independently. These sensors will be calibrated from a single toroidal dc transformer capable of measuring the total current ($e^+ + e^-$) in the ring to an accuracy of 0.1 mA. (Calibration is done with a single beam in the ring.)

The beam-position monitoring system is similar in design to that of SPEAR.[32] It measures the position of the beam in the ring at approximately 80 points. Each monitor consists of four buttons in the vacuum system which couple capacitively to the beam. Comparing the amplitudes of the signals produced by the buttons generates the beam position information.

Two luminosity monitors, one a small-angle, high-rate system and the other a large-angle ($10^\circ$ - $20^\circ$), low-rate system will be provided.

Fast strip-line monitors for the stored beam and injection beam monitors will also be provided.

## G. Beam Parameters

For the sake of concreteness and to avoid confusion in this section, we choose two specific modes of operation of PEP from among those described in Chapter II.A: one for operation at beam energies from 15 GeV down and one for operation at higher energies. The modes chosen are those we consider most likely to be used.

For energies of 15 GeV and lower, we choose to control beam size by means of the wiggler magnets and to use at all energies the same "standard" lattice configuration (Table III). Figure 49 displays the characteristic functions of the standard configuration.

For energies above 15 GeV, we choose the method of variation of tune for the control of beam size.

The horizontal beam emittance in both regimes is shown in Fig. 50. The betatron-oscillation damping time $\tau_\beta$ and its reduction by the wiggler magnets are shown in Fig. 51. (Since the PEP lattice is a separated-function lattice, both the vertical and the horizontal damping times are the same and the longitudinal damping time is one-half of $\tau_\beta$.) Figure 52 gives the design beam current as limited by the beam-beam limit and, above 15 GeV, by the total installed RF power. The currents above 15 GeV depend very much on the momentum compaction factor and therefore on the beam-dynamics configurations. The lattice parameters corresponding to Fig. 52 were scaled from the 15-GeV configuration and the actual configurations used may be somewhat different due to various matching requirements.

Some of the RF parameters are given in Fig. 53 - 56. Included in the calculation of RF and RF-related parameters are the higher-order-mode losses in the cavities and the vacuum chamber, as explained in Section II.C.8. We take the bunch-lengthening factor to be 2 and assume that the vacuum chamber meets the criterion

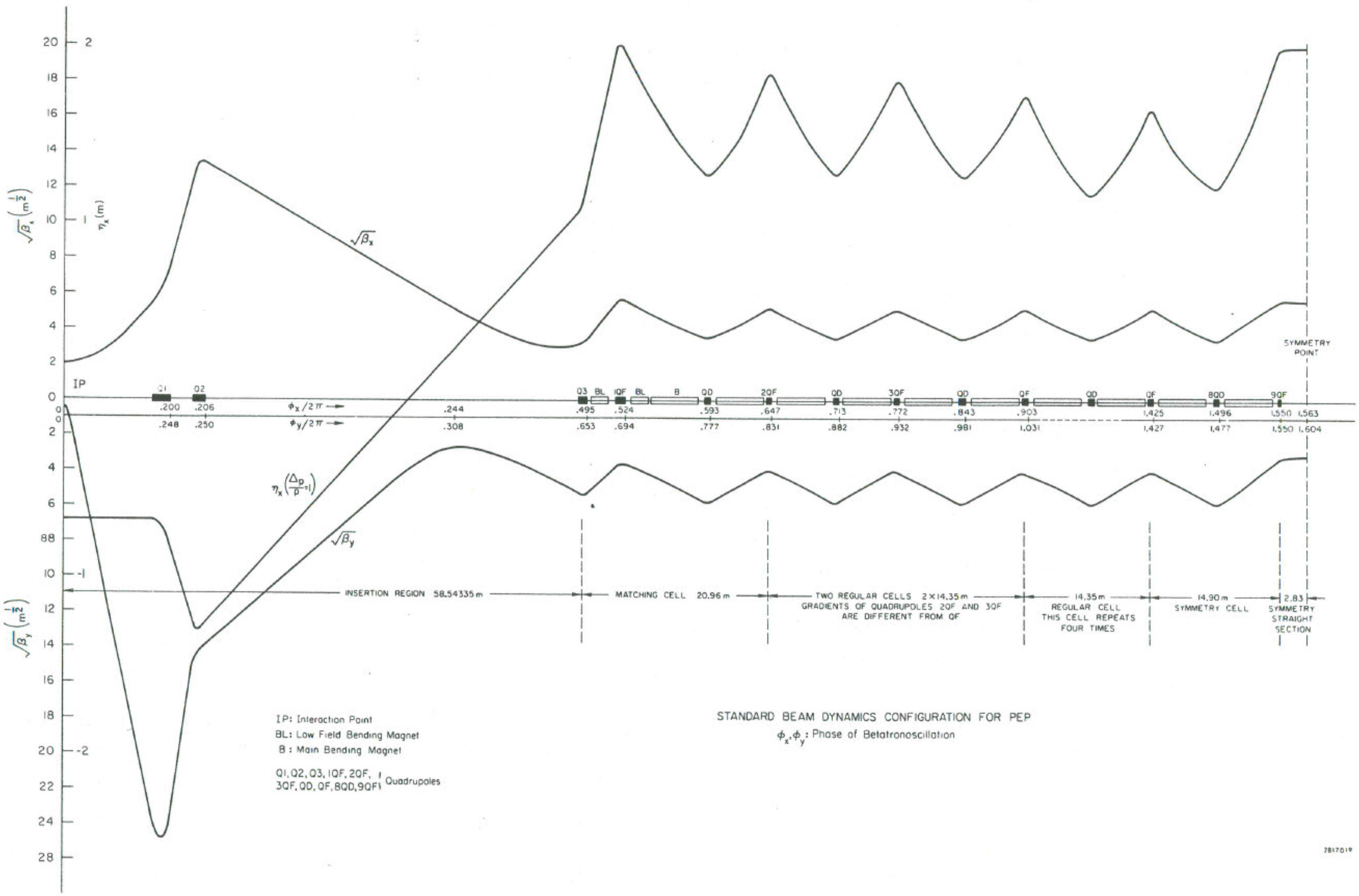


Fig. 49--Betatron and eta function in the standard configurations.

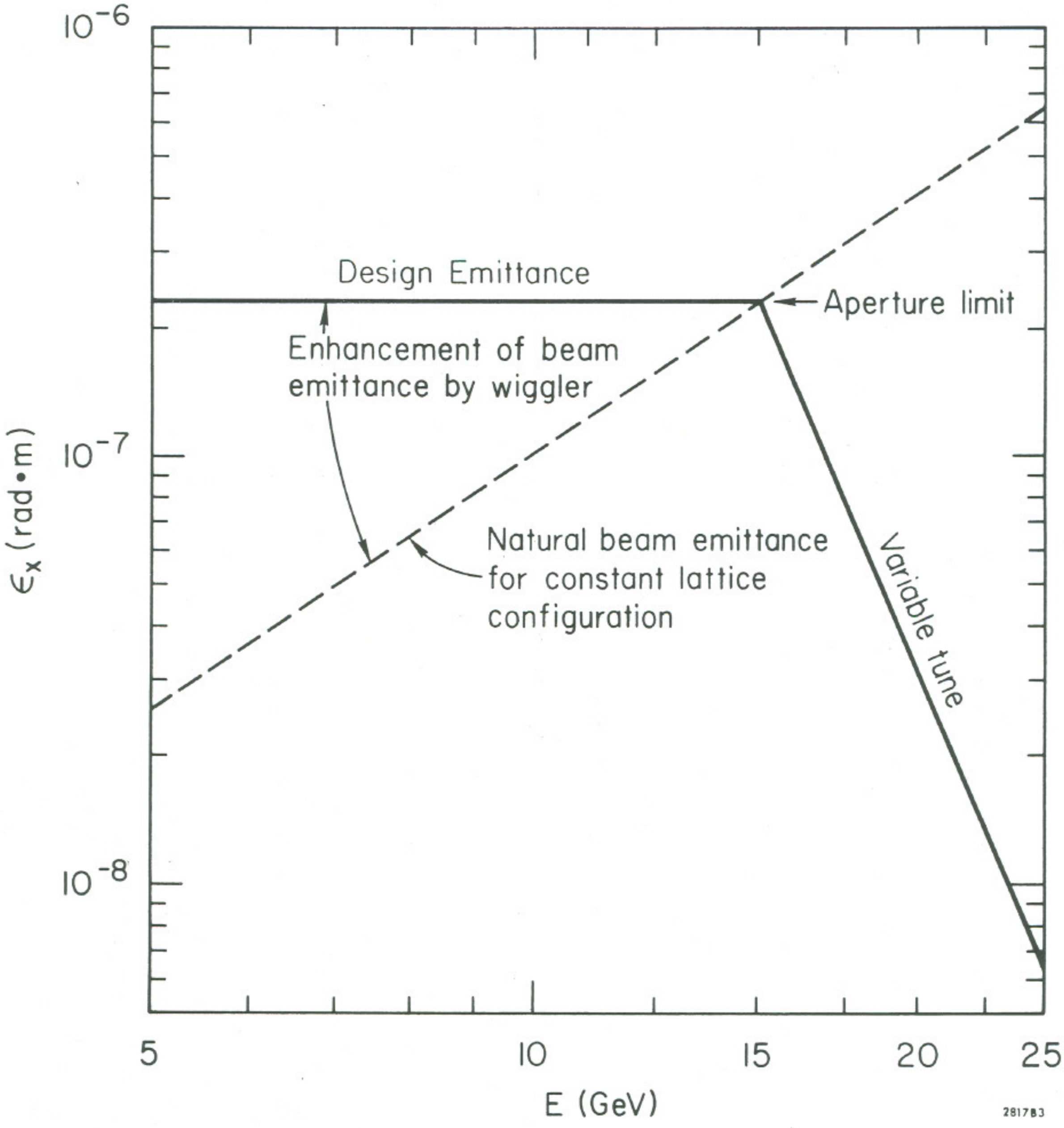


Fig. 50--Beam emittance vs energy.

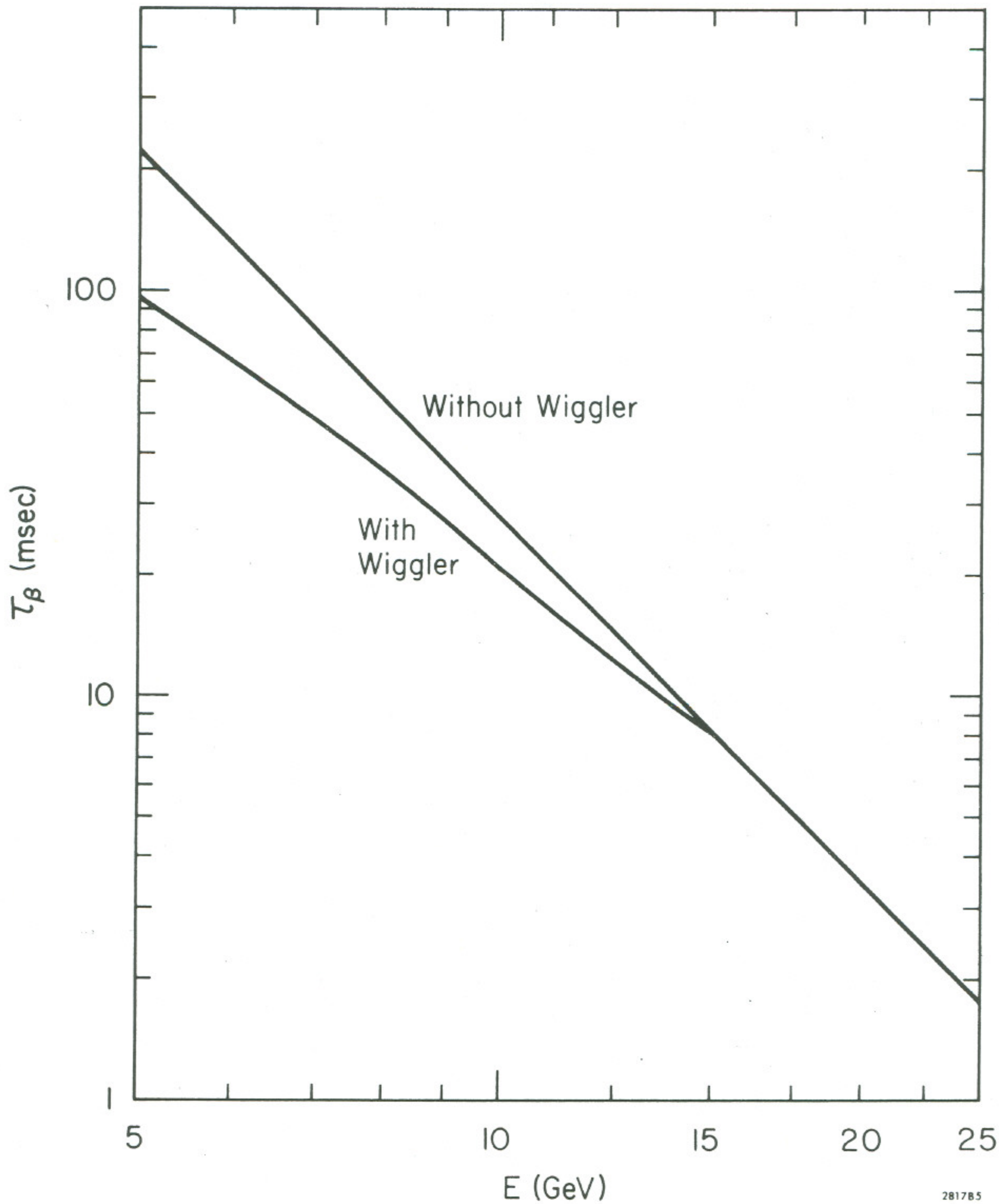


Fig. 51--Betatron damping time vs energy.

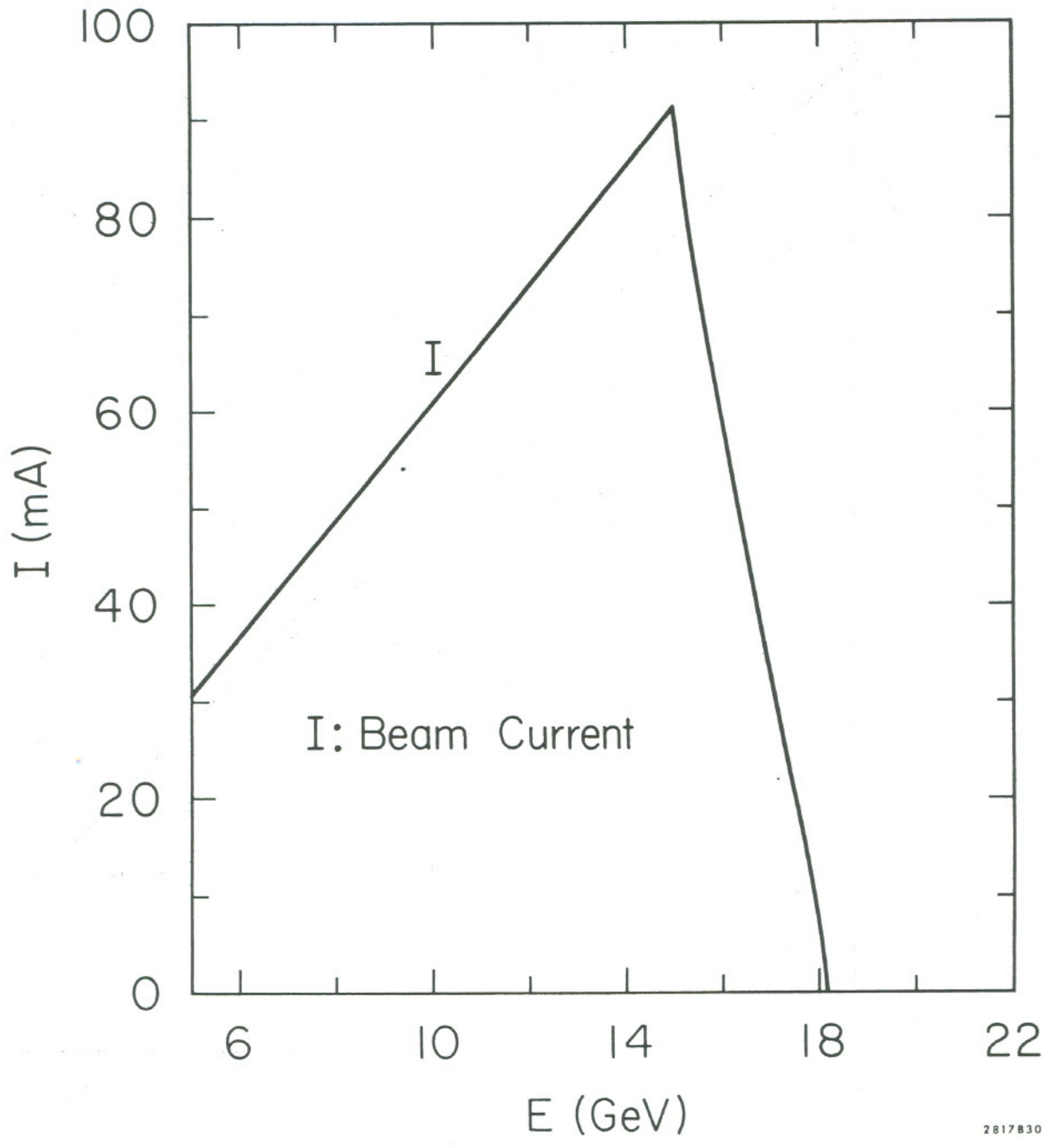


Fig. 52--Design current vs energy.

of being a factor of 10 better with respect to higher-order-mode losses per unit length than the SPEAR chamber.

In the operation of the RF system, there are three principal energy regimes with differing limiting conditions. See Fig. 53.

In the highest regime, above 15 GeV, the storable beam current is limited solely by the available RF power. The peak voltage required to maintain adequate quantum lifetime (50 hours) rises rapidly and, with it, the power deposited in the cavity walls, with the result that the power available to the beam drops off with rising energy. With the power rising and the voltage-per-turn demand rising, the storable current falls dramatically. This fact is reflected in Fig. 52.

In the intermediate regime just below 15 GeV, the storable current is limited by the aperture and the beam-beam limit. As the energy is reduced, less and less RF power is required by the beam so that more is made available for cavity losses.

In the lowest energy regime, below about 14 GeV, the dominating consideration is maintaining the energy aperture at ± 1% for good injection rate.

The energy spread ($\sigma_\epsilon / E_0$) in the beam stays constant up to 15 GeV and increases above 15 GeV. See Fig. 54. A bunch-lengthening factor of 2 is assumed in calculating the bunch length $\sigma_z$. This factor of 2 is a guess at the real bunch lengthening with energy and current based on a rough extrapolation from SPEAR. The synchrotron oscillation tune and the momentum compaction factor are shown in Fig. 55. In Fig. 56, the total RF power consumption by both beams and its composition in terms of synchrotron radiation power, fundamental-mode cavity losses and the higher-order-mode losses are shown.

Figure 57 shows the calculated total beam lifetime and several of the most significant partial lifetimes. The total lifetime under colliding-beam conditions

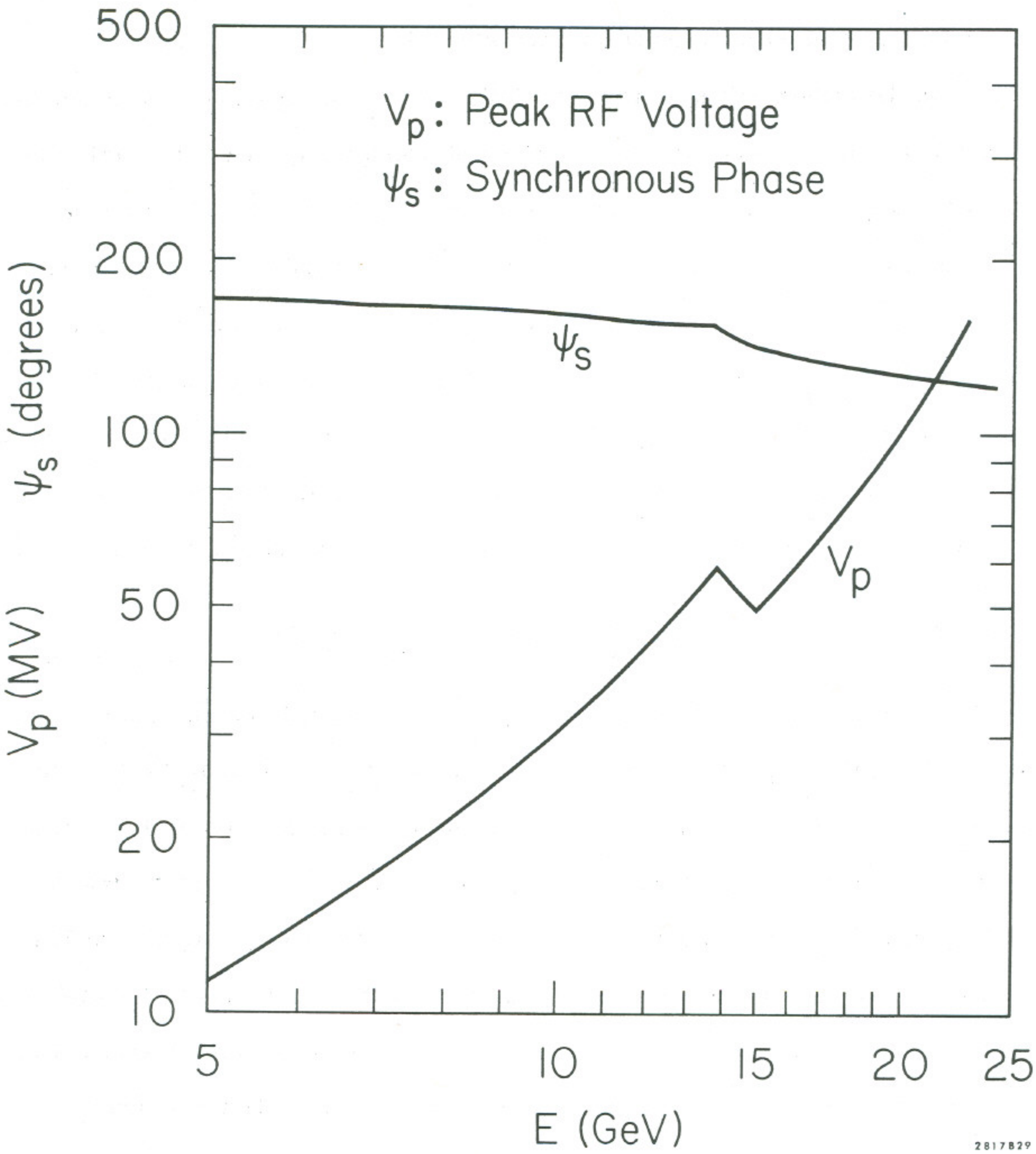


Fig. 53--RF peak voltage and synchronous phase vs energy.

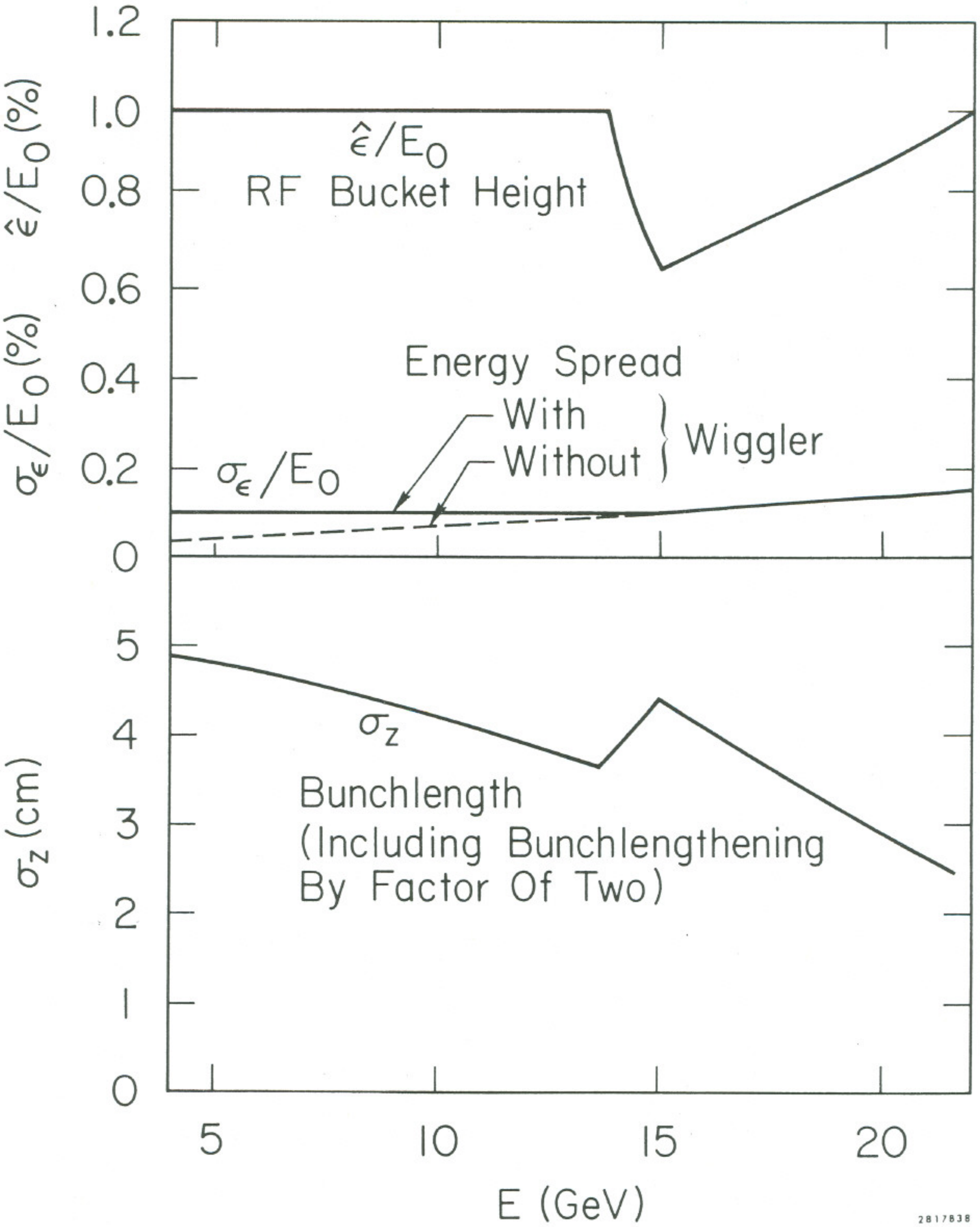


Fig. 54--RF bucket height, energy spread in the beam, and bunch length vs energy.

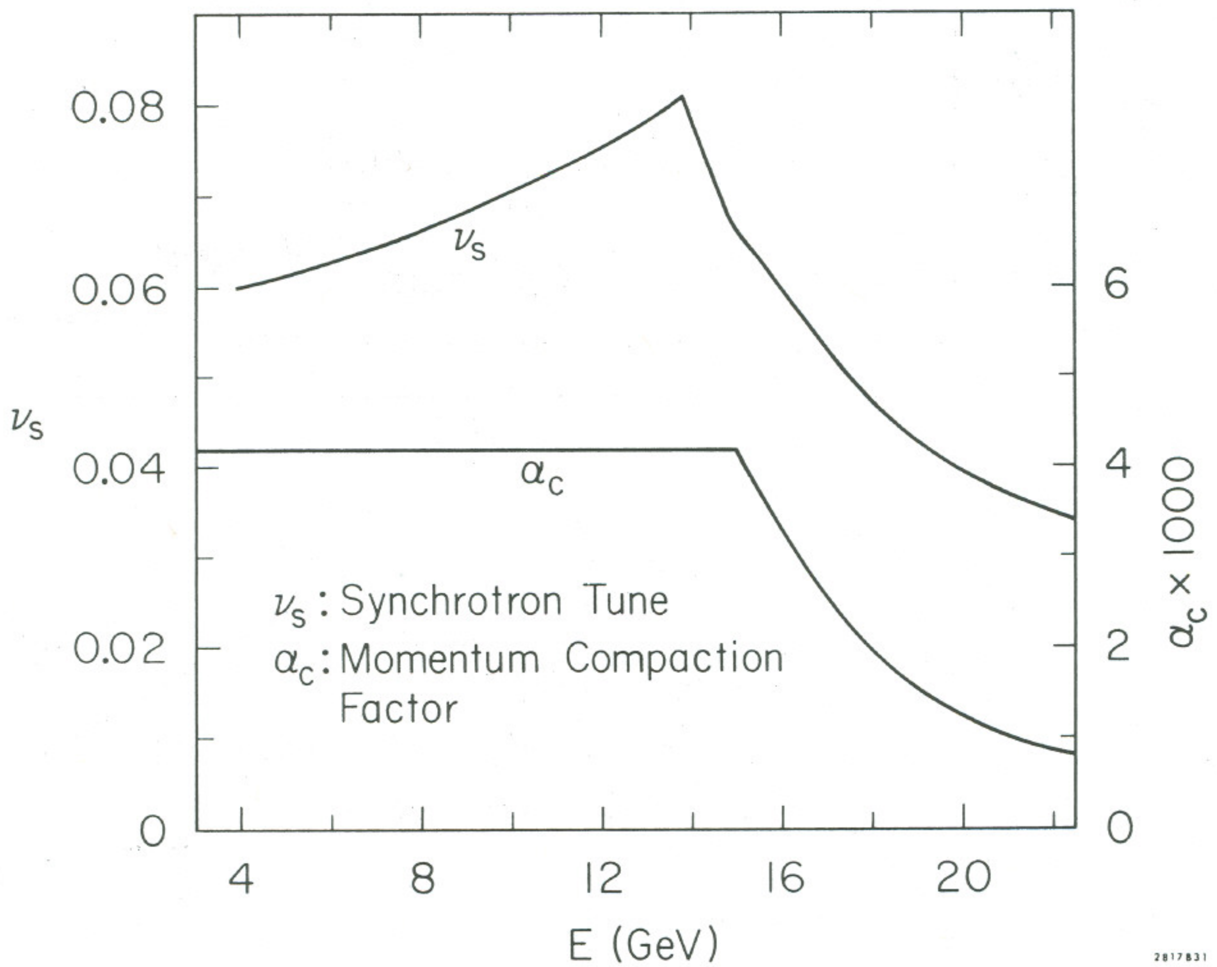


Fig. 55--Synchrotron oscillation tune and momentum compaction factor vs energy.

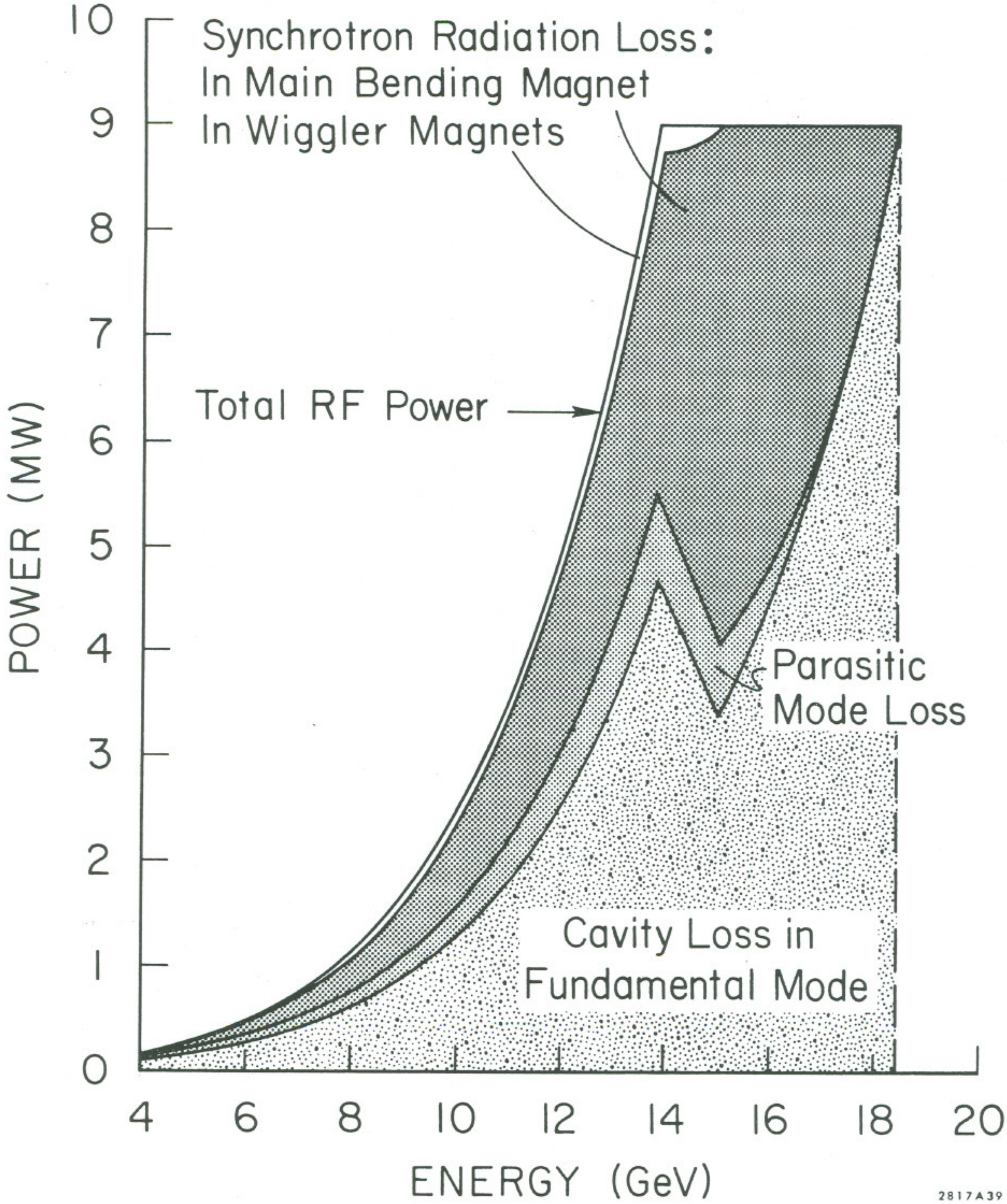


Fig. 56--RF power distribution vs energy.

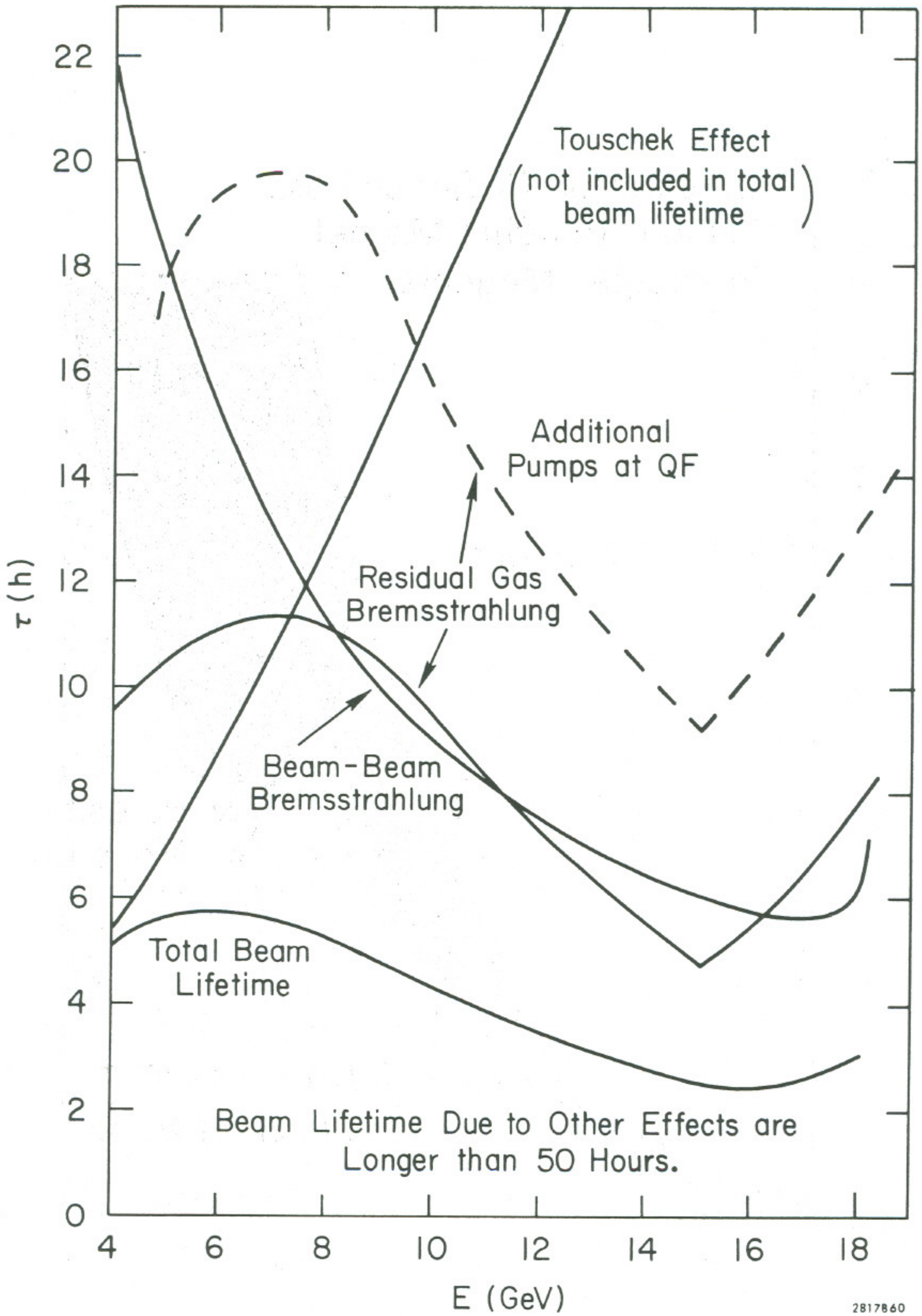


Fig. 57--Beam lifetime vs energy.

is dominated by residual-gas bremsstrahlung and beam-beam bremsstrahlung. The former is independent of the transverse blow-up of the beams in collision. The latter is calculable without knowledge of the details of the blow-up if the values of the stored current and the luminosity are known. By contrast, the intra-beam scattering (Touschek Effect) lifetime is strongly dependent on the blow-up. The Touschek partial lifetime for a single (i.e., non-colliding) beam at natural dimensions is shown for comparison in Fig. 57; however, it is not included in the total beam lifetime calculation because it becomes negligible when the beams collide and blow up. All effects other than residual-gas and beam-beam bremsstrahlung contribute together less than 5% of the total lifetime.

The dashed line in Fig. 57 shows the improvement which could be obtained in the residual-gas bremsstrahlung partial lifetime by adding additional vacuum holding pumps at all QF quadrupole magnets. The potentiality of adding these pumps will be retained as design progresses as a safeguard against unexpectedly high desorption rates and a possible future improvement in average luminosity.

# III. PHYSICAL PLANT

## A. General Features of the Terrain and Their Effects on Construction Techniques

### 1. Tunnel Design and Construction

Visualize the PEP ring in plan view as a regular hexagon with broadly rounded corners (see Figs. 1 and 58). In this discussion, the rounded corners will be referred to as arcs and the straight sides will be termed insertions.

The arcs are to consist of two curved sections, each 122 m long and joined in the middle by a short straight section (symmetry insertion) 5.66 m long. The six major insertions are 117 m long with the beam interaction points at their centers.

The ring plane is horizontal and lower than the linear accelerator horizontal plane by 10 m. It is located so that the vertical plane of the accelerator bisects it in a west-to-east direction through two of the arcs, the westernmost being 118 m beyond the end of the accelerator. This arrangement is chosen to allow the two injection beams from the accelerator to be symmetrical.

Since the hexagon comprises twelve major parts, it is convenient to label these parts as Regions 1 through 12 in analogy to a clock's face with Region 1 the northeast arc, Region 2 the northeast insertion and so on around to Region 12 which is the northernmost insertion. Frequent reference to these regions occurs in the material which follows.

The terrain of the site varies in elevation by as much as 30 m. It is highest along the accelerator axis and slopes away to both the north and the south. Consequently, most of the interaction regions will lie in low areas. The centerline of the ring housing (not to be confused with the beam path) as shown in Fig. 59 is to be at an elevation of about 66 m above mean sea level and will pass about 10 m below the floor of the SLAC beam switchyard.

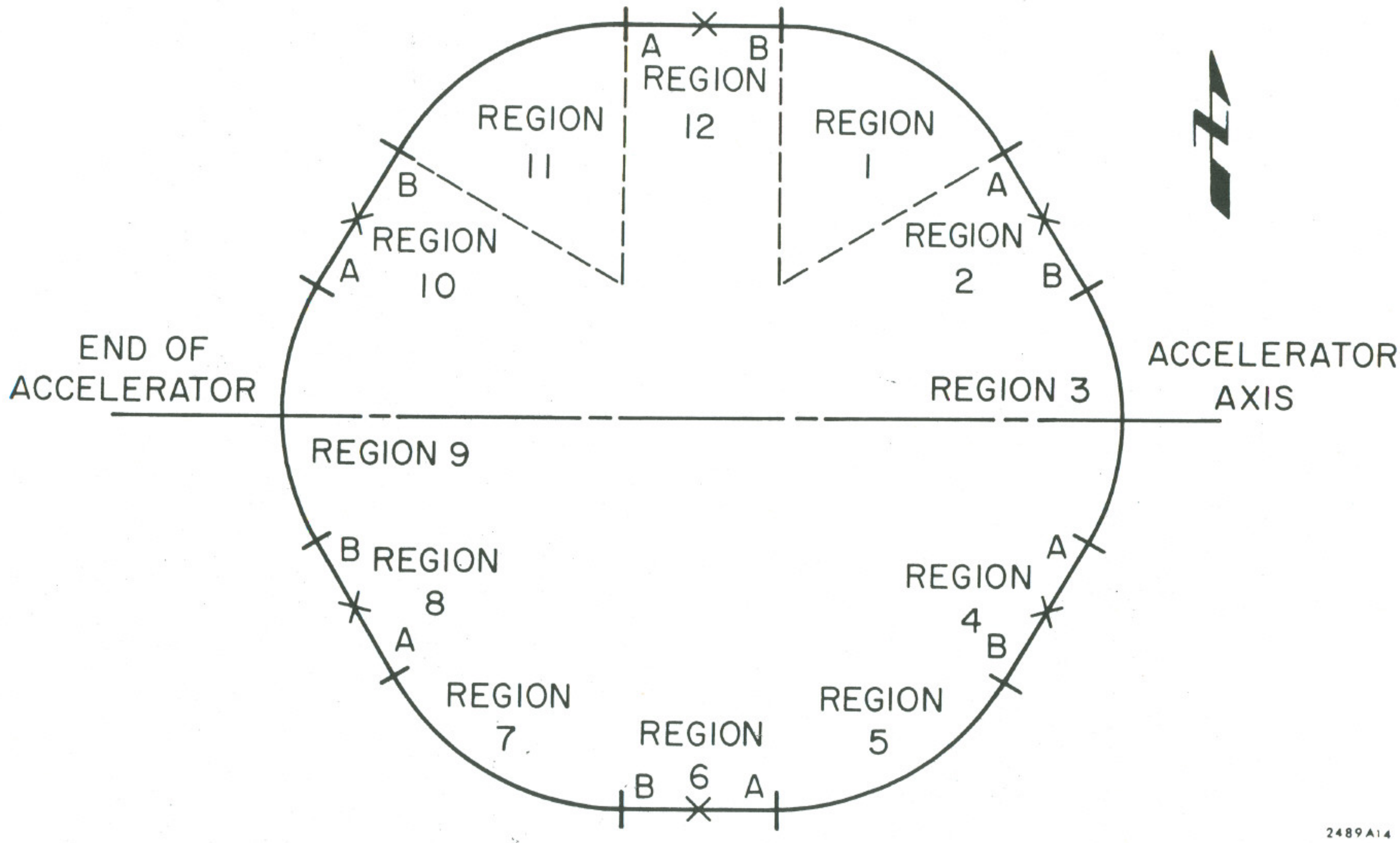


Fig. 58--PEP region numbering system. The accelerator beam is defined to run from west to east with Region 12 on the north side.

The prevailing low terrain suggests that the ring housing between Interaction Points 4 and 6, and a short length west of Interaction Point 6 be constructed by cut-and-cover methods. The ring housing in Region 1 may also be of cut-and-cover construction. Elsewhere the ring housing will be constructed by bored tunnel methods. The structures and facilities to be provided for research are described in detail in Chapter IV.

Each of the two injection beam transport tunnels will be joined to the linear accelerator housing at acute angles a short distance downstream from the end of the accelerator. They will branch away and downward, the southern run joining the PEP housing near the junction of Regions 8 and 9 and the northern run near that of Regions 9 and 10. The injection beams themselves will join the storage ring tangentially and from overhead (Fig. 45). Each of the transport tunnels will be about 112 m long. Junctions with the accelerator housing and the ring housing will probably be made by means of large, jacked pipes totalling 45 m in length to minimize jeopardy to existing housings and excessive interruption of regular SLAC operation during construction. The diameter of the injection tunnels will probably be smaller than the diameter of the ring tunnel. This fact together with access conditions suggests construction by hand-mining methods. The structures at junctions with the ring will be of a complicated nature, providing some of the project's most challenging underground construction problems.

The ring tunnel must be large enough to provide space for the electron-positron storage-ring components, cooling system piping and drainage piping, magnet power cables, instrumentation cabling and potential future proton beam hardware, plus suitable aisle space. Present plans call for the $e^+$-$e^-$ beam components to be suspended from the floor of the tunnel. In the event that a proton ring is added later the $e^+$-$e^-$ beam will be relocated so as to pass alternately above and below it, crossing in vertical planes at the interaction points. (See Appendix A.) Provision for a possible future synchrotron radiation experimental facility will also be built into the tunnel. Alternative locations are being evaluated.

Bored tunnel sections will be constructed by soft-ground tunneling methods. Most of the tunnel will be in loosely-consolidated and fine-grained Miocene sandstone. There will be limited areas of uncemented sand which will require especially sturdy initial support. Extensive core-boring and analysis around the periphery of the ring indicates that the tunneled portion of the ring housing will require shield-tunneling methods.

A minimum inside diameter of 3.35 m will be required for the bored tunnels (Fig. 59). However, this dimension, while allowing the necessary space, would require close alignment tolerance of the tunnel centerline; for this reason, a larger tunnel with a more relaxed centerline tolerance might prove less costly.

The finished tunnels will be concrete-lined and painted white for good working light levels and to reduce concrete dusting. Careful concrete-mix design specification and quality control will be exercised, not only to minimize cracking due to dimensional changes caused by unavoidable temperature differences but also to allow for the high sulfate content of the soil and ground water.

Initial support for the tunnels may be provided by steel sets and lagging, rock bolts and spiling, precast concrete sections or shotcrete. The ability to resist the thrust of the shield will be an important determining factor.

In order to suspend beam components from the tunnel roof, special reinforcing will be built into the tunnel's room lining and suspension provisions will be cast in.

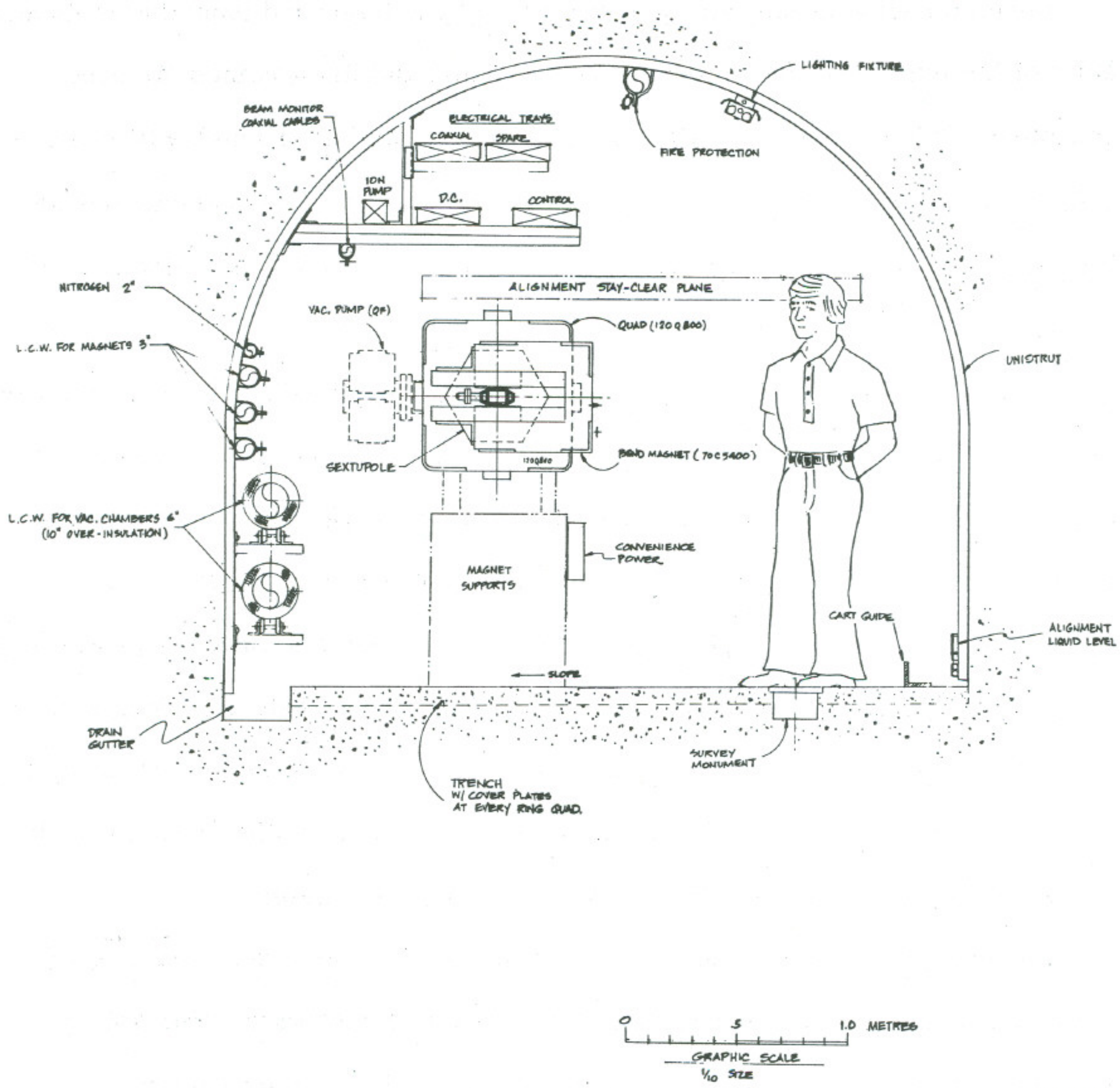


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Fig. 59--Tunnel cross section.

To avoid delaying installation and the expense and bother of in-transit warehousing and double-handling, parts of the ring housing will be scheduled for early completion. We will establish three simultaneous tunnel operations, two in the main ring and one in the beam transport tunnels. Scheduling of research-facility construction in the interaction areas will be arranged so that the beginning phase will create portal structures for tunneling. When the tunnels are finished and the portals are no longer needed, the halls will be completed.

2. Roads

About 3.0 km of additional roads will need to be added to the present SLAC road system. Very little heavy earthwork is entailed due to the gently rolling nature of the site. Typical roads will have 20-ft traffic ways with 5-ft shoulders, and maximum grades will be about 8%. Oil-and-rock-chip seal coats will be used over aggregate base courses ranging between 6 and 10 inches in thickness, varying somewhat with subgrade conditions. Permanent surfacing will be done after construction.

3. Earthwork and Erosion Control

Side slopes will be constructed no steeper than 2:1 and will be flatter in areas of prominent visibility. Where space is limited special measures will be taken to enhance appearance. Erosion control surface treatment and early seeding will be done to enable the results to blend into the natural landscape. Adjacent to building areas, ground covers such as ivy, ice plant, etc., will be used not only for appearance but to reduce fire hazards as well. Edges of earthwork sections will be generously rounded to blend into the natural terrain. Any surplus materials will be used in smooth, free-form mounds for sight screening.

During the construction period, temporary silting ponds will be so placed in drainage channels to prevent silt flow into Menlo Park's drainage systems to the north and onto the flat horse-training areas to the south. Sprinkled water will be used as required to reduce dust during construction. Topsoil will be stripped from all areas to be regraded, saved and placed on finished surfaces as part of the erosion control treatment. Material will be hauled from the northern to the southern part of the ring to provide the large quantity of material required by the shielding fills in Region 5. In so doing we will avoid unnecessary excavation.

4. Drainage

High-reliability pumping systems with emergency power provisions will be used to drain the pits of the experimental areas and the lower yard of Region 2. Other yards will be served by gravity pipe systems. Erosion control measures will be taken at drain outlets wherever they are needed. Interceptor ditches, usually asphalt-lined or concrete-lined, will be constructed in peripheral areas around yards to minimize loads on the pumping systems and the storm drains. All ditches, canals and other waterways will be so constructed as to prevent erosion.

5. Landscaping

Throughout most of the construction area, regraded terrain will be treated to assure an early return of the natural grass growths of the site. Around building areas, shrubbery, trees and ground covers will be established early with sight screening a primary consideration.

Groves of eucalyptus, Monterey pine, and other fast growing trees will be used for large stands of sight screening. Drought-resistant plant materials will be used for the most part; however where water is necessary to establish the plants, temporary pipe systems will be laid on the surface. Limited areas where less drought resistant plants are used will be provided with permanent sprinkler systems.

6. Sanitary Sewers

Sewage from Regions 12 and 2 will flow by gravity systems to SLAC's existing metering station on the Menlo Park Sanitary District system. Regions 4, 6 and 8 will be served by piped systems connecting to an existing sewer on University land which also leads into the Menlo Park system.

7. Surface Buildings

Surface buildings to house instrumentation and control equipment, RF power equipment, toilet facilities, etc., will be located near the interaction areas. RF facilities will be located in Regions 4, 8 and 12, and instrumentation and control housings will be required at all interaction areas. Economical construction will be used but architecture and landscaping will conform to rural aspect of the site. A schematic layout of the surface buildings and utility systems for each interaction region location and for the beam transport lines is shown in Figs. 60 to 66. The internal layout for the RF and instrumentation and control building for Region 8 is shown in Fig. 67.

A large vacuum system assembly building will be required at SLAC's present shop area. It will be of steel construction, conforming to SLAC's present architectural standards.

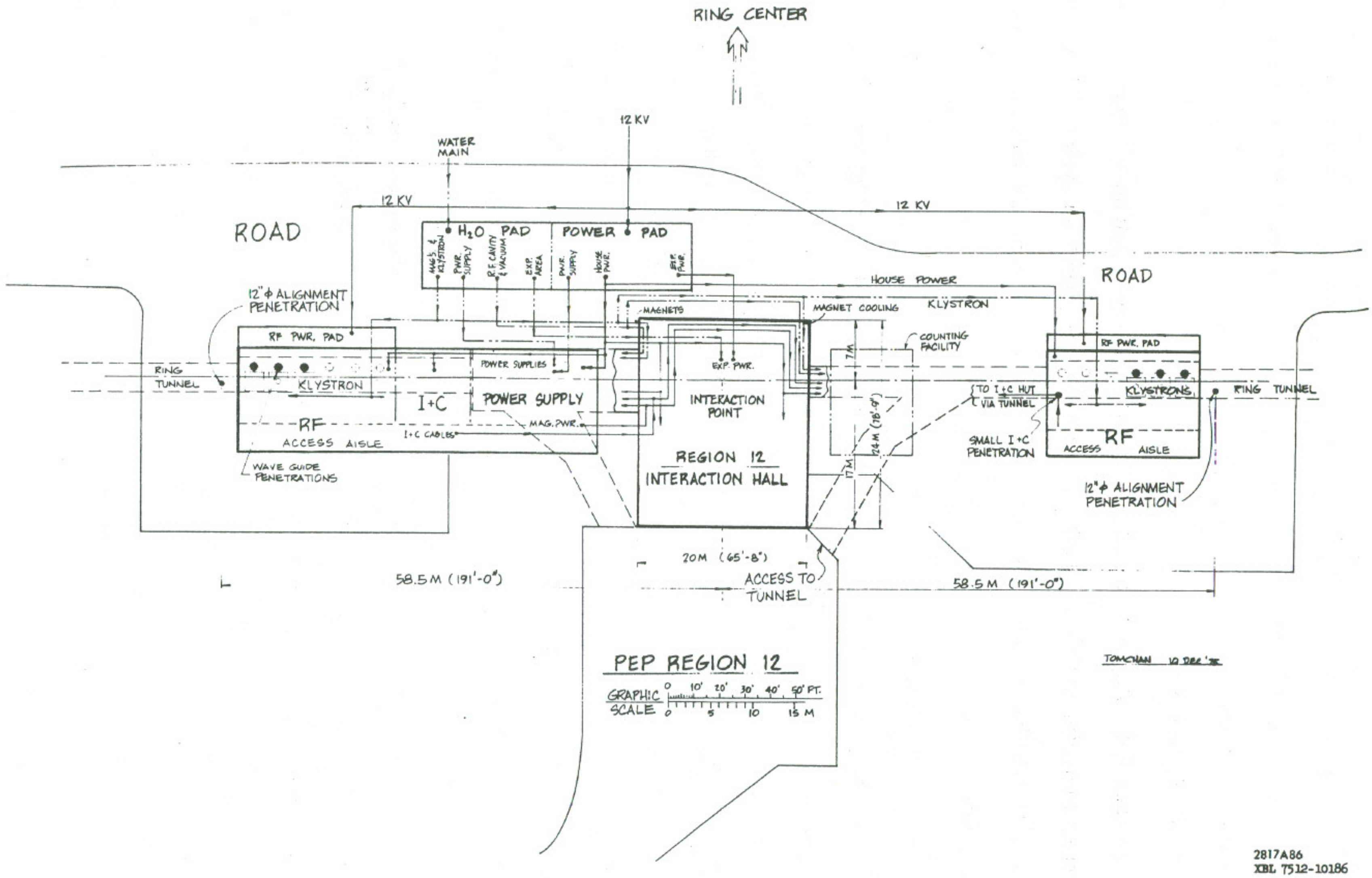


Fig. 60--Region 12 surface buildings and utilities.

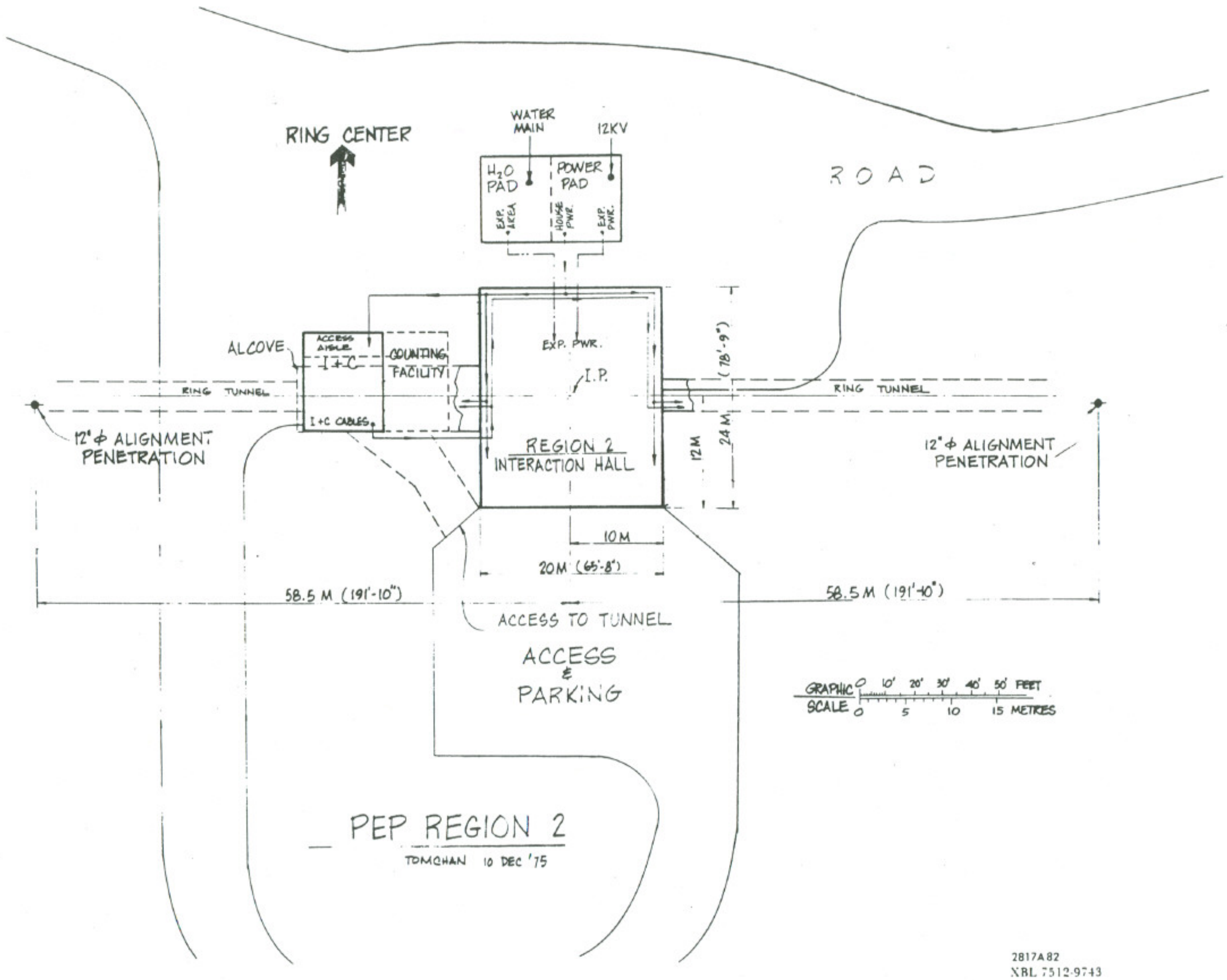


Fig. 61--Region 2 surface buildings and utilities.

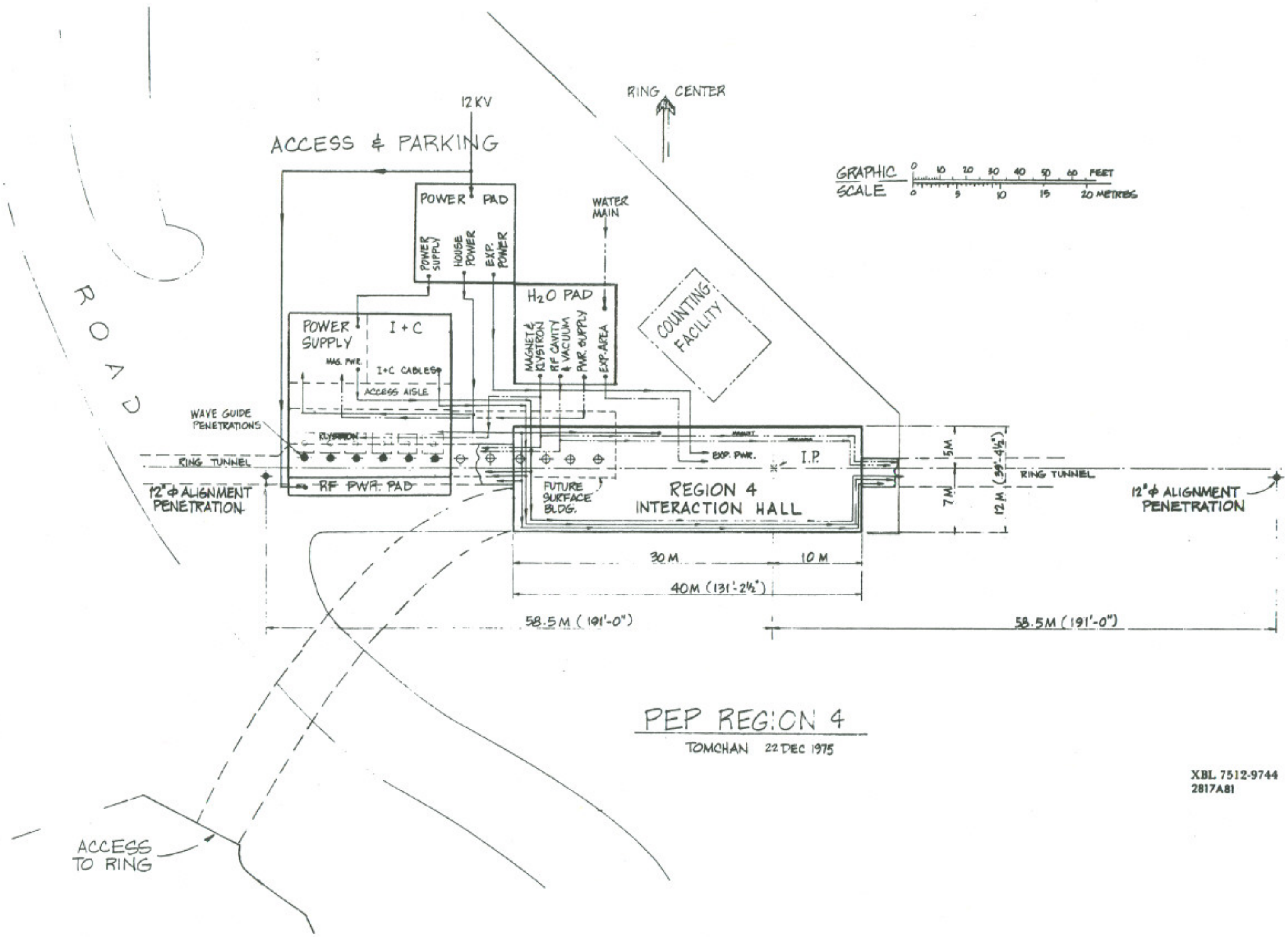


Fig. 62--Region 4 surface buildings and utilities.

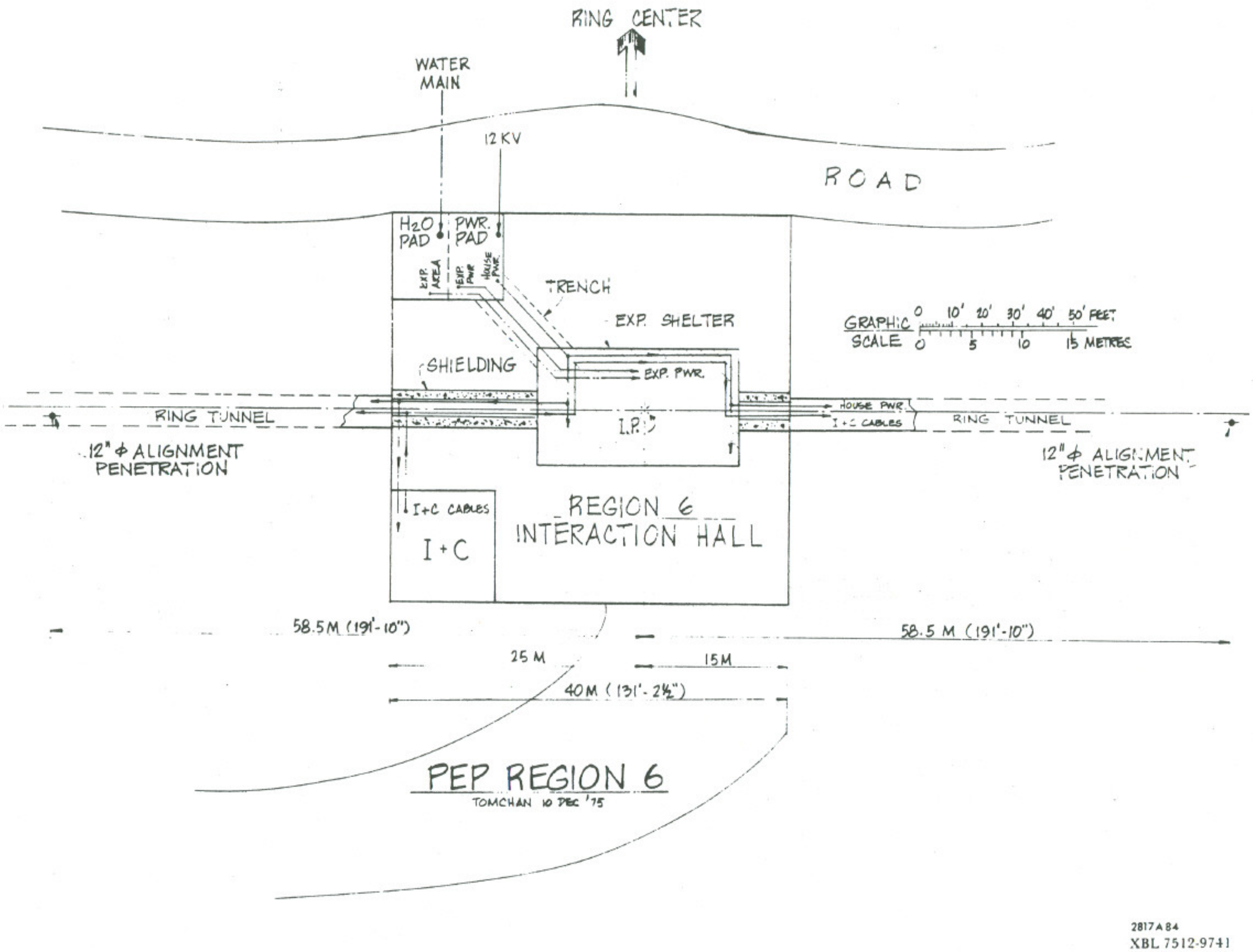


Fig. 63--Region 6 surface buildings and utilities.

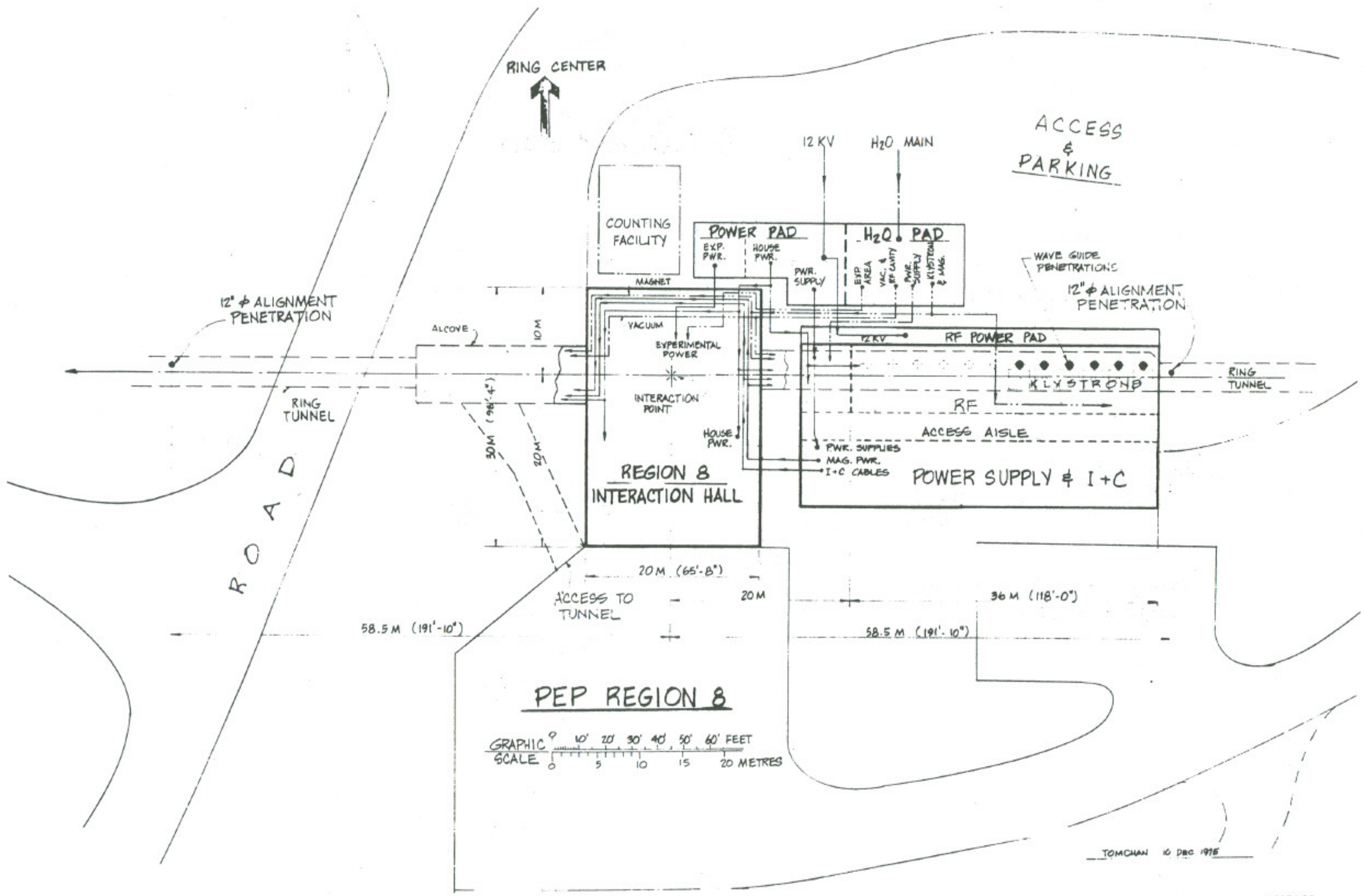


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Fig. 64--Region 8 surface buildings and utilities.

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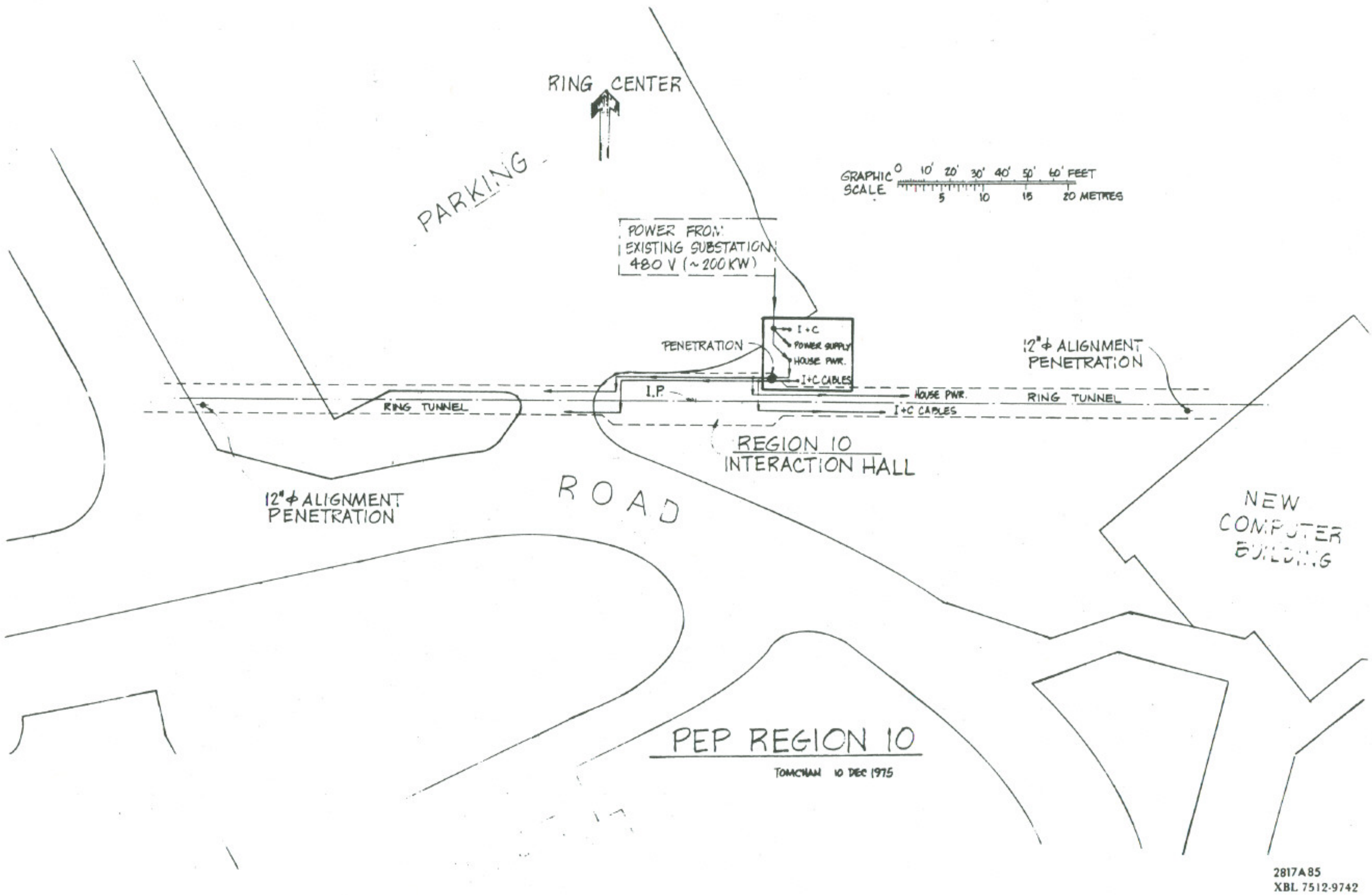


Fig. 65--Region 10 surface buildings and utilities.

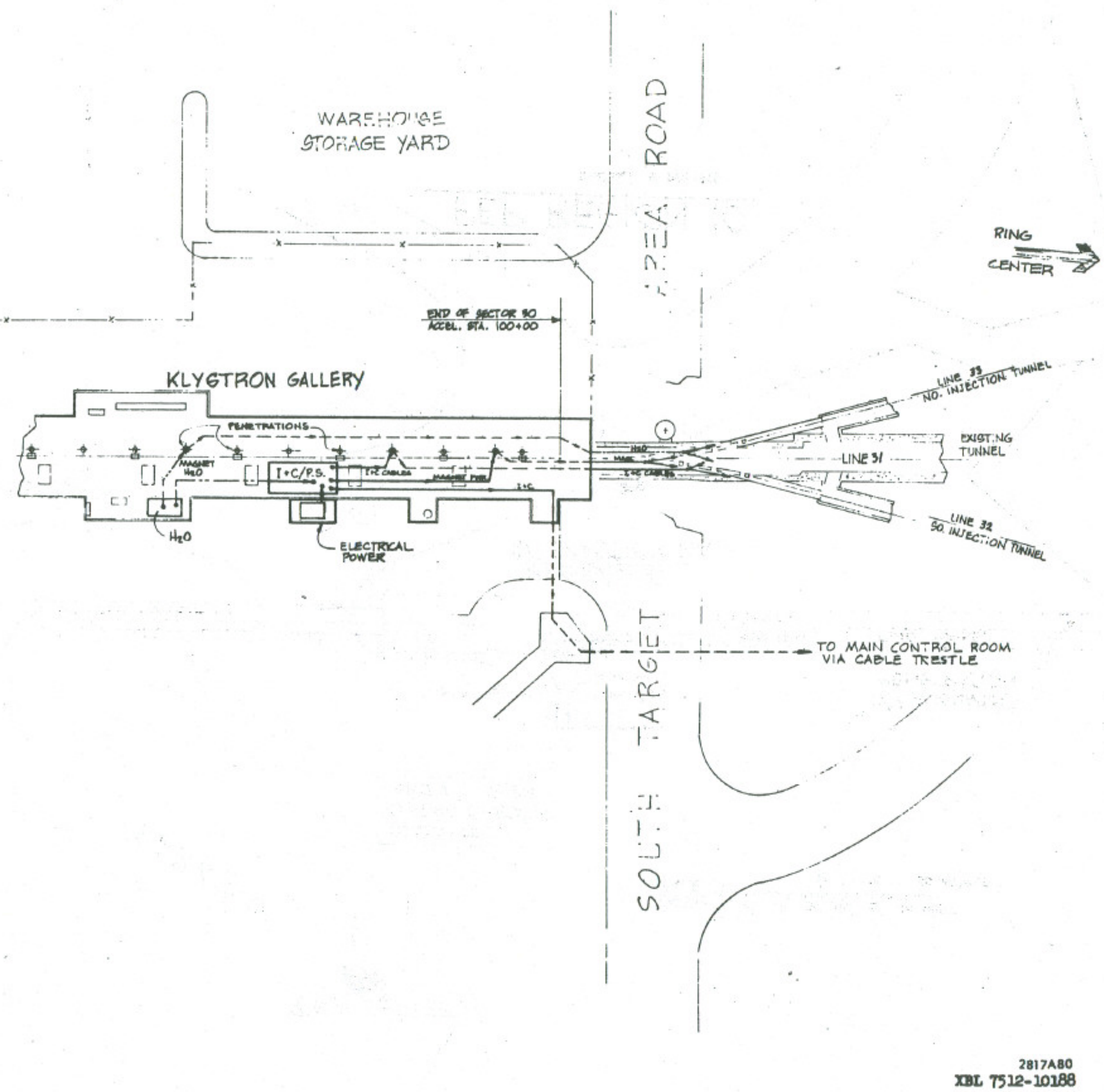


Fig. 66--Sector 30 surface buildings and utilities.

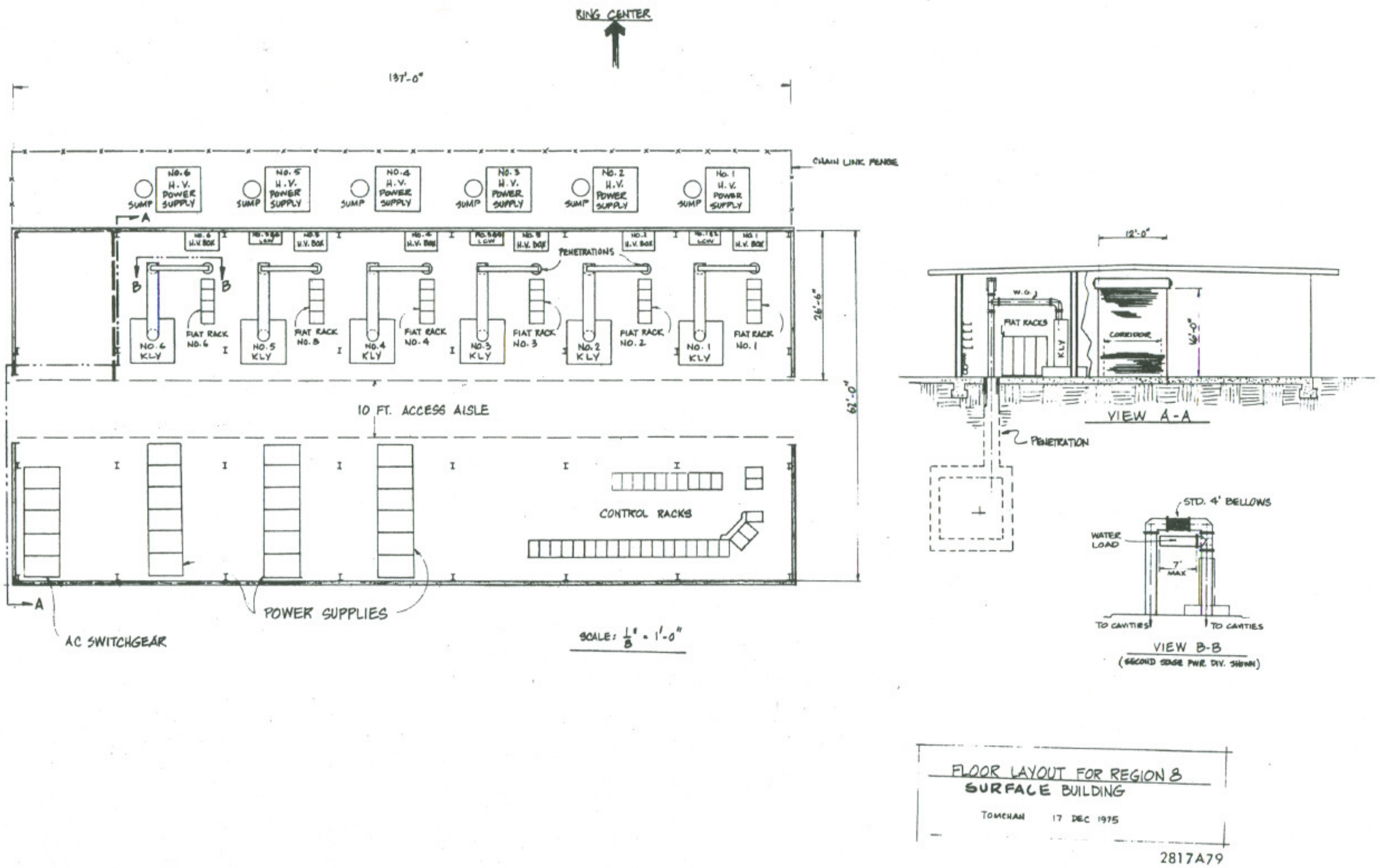


Fig. 67--Floor layout for Region 8 surface buildings.

## B. Utilities

### 1. Electrical Facilities

The maximum electrical power demand for the electron-positron storage ring and experimental apparatus is estimated at 30 MW for the maximum PEP design energy of 18 GeV. This project power demand is based on the regional loads of all PEP components which are compiled in Table XIV. It should be noted, however, that PEP will ordinarily operate at various energies below 18 GeV with varying experimental loads. Therefore the average power utilization will be considerably below the 30 MW maximum demand figure.

Existing SLAC Power System. SLAC presently receives power from two sources:

(1) A 230-kV line with a line capacity of 300 MW. At present a single stepdown main transformer is rated 50/66/83 MVA and the secondary is operating at 12.47 kV with grounded wye.

(2) A standby 60-kV line with a limited line capacity of 18 MW. It is equipped with two 10.7/15.4/18 MVA stepdown transformers, and the secondary is also operating at 12.47 kV with grounded wye.

The 12.47-kV systems from the above two sources are not electrically synchronized in phase; consequently they cannot operate in parallel. Normal operations of the SLAC system are supplied from the 230-kV source with the tie breaker closed and the 60 kV system serving as a standby. (See schematic in upper right corner of Fig. 68.)

PEP Primary Power Loops. Two 12.47-kV underground feeder circuits will be installed in duct banks around the inside of the PEP ring following the trench for the main loop of the water system described in the next section. The two PEP circuits will be fed from two existing Beam Switch Yard (BSY) feeder

TABLE XIV

PEP Power Requirements at 18 GeV (kW)

| Region Location | 12 | 2 | 4 | 6 | 8 | 10 | Sector 30 | Total Demand by Components | Total[a] Demand to Power Supply |
|---|---|---|---|---|---|---|---|---|---|
| SYSTEM | | | | | | | | | |
| 1. Magnets and Buses | | | | | | | | | |
| Main Dipoles [b] | 500 | | 500 | | 500 | | | 1890 | 2224 |
| Q1 and Q2 [b] | 130 | | 130 | | 130 | | | | |
| Q1-Q2 Trim [c] | 10 | 10 | 10 | 10 | 10 | 10 | | 60 | 70 |
| QF's and QD's [c] | 280 | | 280 | | 280 | | | 840 | 988 |
| All other Quads [c] | | | | | 1250 | | | 1250 | 1470 |
| Sextupoles | | | | | 300 | | | 300 | 353 |
| Wiggler | | | | | (180) | | | 0 | 0 |
| Correction Elements | 30 | 30 | 30 | 30 | 30 | 30 | | 180 | 212 |
| Injection Magnets[d] | | | | | | | 760 | 760 | 895 |
| (Magnet Subtotal) | (950) | (40) | (950) | (40) | (2500) | (40) | (760) | (5280) | (6210) |
| 2. Rf System | 3000 | | 3000 | | 3000 | | | 9000 | 15000 |
| 3. Experimental Equipment[e] | 850 | 850 | 850 | 850 | 850 | ~100[f] | | 4350 | 5120 |
| 4. House Power[g] | | | | | | | | | |
| Tunnels | 40 | 40 | 40 | 40 | 40 | 20[f] | 50 | 270 | |
| Interaction Halls | 35 | 35 | 35 | 35 | 45 | 10 | | 195 | |
| Surface Buildings | 100 | 60 | 100 | 70 | 110 | 50[f] | 20 | 520 | |
| MCR | | | | | 50[f] | | | 50 | |
| (HP Subtotal) | (175) | (135) | (175) | (145) | (245) | (80) | (70) | (1035) | 1035 |
| 5. Mechanical Utilities | | | | | | | | | |
| LCW Systems | 400 | 60 | 400 | 60 | 420 | 0 | 150 | 1490 | 1490 |
| Cooling Towers | | | | | 1200 | | | 1200 | 1200 |
| TOTAL | 5375 | 1085 | 5375 | 1095 | 8215 | 220 | 980 | 22345 | 30055 |

NOTES:

[a] Projects overall magnet power supply efficiency of 85% and overall rf system's efficiency of 60%.

[b] Dipoles and insertion Quads, Q1Q2, are in series.

[c] Based on 120 mm design for normal cell quads. (The potential 100 mm bore design being studied can provide ~700 kW power reduction.)

[d] For operation at 15 GeV.

[e] Actual demand per area can be 3 × 850 kW with the total power for all areas constrained to 4350 kW.

[f] Assumes power from existing substations.

[g] Power for lights, electronics, cranes, convenience outlets, etc.

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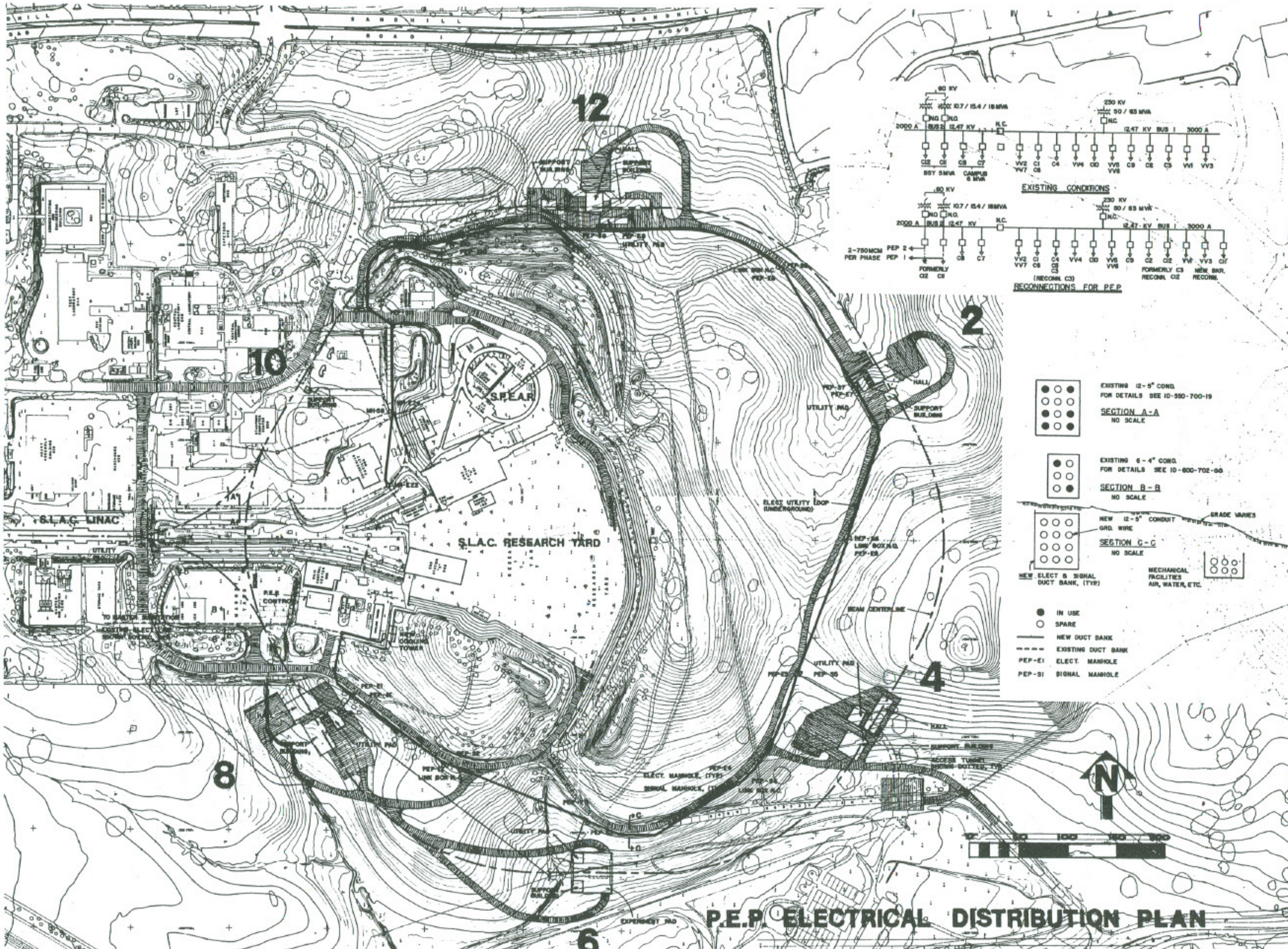


Fig. 68--Electrical research area.

breakers. The presently used BSY circuits will be reconnected to Master Substation Bus No. 1 as indicated in Fig. 68. Some of the existing duct banks (light dashed line in the figure) will be used to connect the PEP loops which are indicated by the heavy dashed lines.

Principal Services. The PEP 12.5-kV main power loop will feed substations at Regions 12, 2, 4, 6, and 8. The major services are summarized in Table XIV and shown schematically in Figs. 60 to 66.

At regions 12, 4, and 8 the 12.5-kV loop will feed the transformer pad and the klystron power supplies adjacent to the rf building. There are six 820-kVA high voltage klystron power supplies at these regions. Each supply will be fed by three 69-kVA single-phase feeder regulators rated 13,800 volts 95 kV BIL with taps for 13,800-12,000 volt operation. To provide the variable voltage requirements for the RF system, these feeder voltage regulators are equipped with 32 steps 5/8 % each to provide ±10% voltage control. To supply all 18 klystron power supplies as now planned, there will be a total of 54 such feeder regulators installed.

The magnet power supplies, house power (including instrumentation and control power, building and tunnel lights) and the pumps for LCW system will be fed via the transformer pads connected to the 12.5 kV-loop at each interaction region. A preliminary arrangement is summarized in Table XV . A portion of the total 5120 kW (from Table XIV) experimental equipment power is supplied within the transformer capabilities indicated (no 480-volt capability was initially available in previous designs). It is expected that additional transformers will be added as required for experimental apparatus and the 12.5-kV feeders will be capable of supplying up to 3 MVA of experimental power at each interaction point.

TABLE XV

PEP Power Requirements (18 GeV) by Area

| Region Location | System | Maximum[1] Power Demand (kW) | Approx.[2] Line Requirement KVA | Area Sub-Station Transfers |
|---|---|---|---|---|
| 12 and 4 | Magnets | 1120 | 1315 | - One 1500 kVA (12.5 kV - 480 V) |
| | R.F. | 5000 | 5880 | - 12.5 kV Step Regulators |
| | Exp. Equip. | 1000 | 1175 | - One 1500 kVA (12.5 kV - 480 V) |
| | House Power | 175 | 205 | One 300 kVA (480-208/120 |
| | Mech. Utilities | 400 | 470 | Two 75 kVA (480 - 120) |
| 2 and 6 | Magnets | 47 | 55 | - One 1500 kVA (12.5 kV - 480 V) |
| | Exp. Equip | 1000 | 1175 | One 300 kVA (480 - 208/120) |
| | House Power | 140 | 165 | Two 75 kVA (480-120) |
| | Mech. Utilities | 60 | 70 | |
| 8 | Magnets | 2940 | 3450 | - Two 2000 kVA (12.5 kV - 480 V) |
| | R.F. | 5000 | 5880 | - 12.5 kV Step Regulators |
| | Exp. Equip. | 1000 | 1175 | - Two 1500 kVA (12.5 - 480 V) |
| | House Power | 245 | 290 | One 300 kVA (480 - 208/120) |
| | Mech. Utilities | 1620 | 1900 | Two 75 kVA (480 - 120) |
| 10 | Magnets | 47 | 55 | From Existing Sub-station |
| | Exp. Equipment | 120 | 140 | |
| | House Power | 70 | 80 | |
| Sector 30 | Magnets | 895 | 1050 | - One 1500 kVA (12.5 - 480 V) |
| | House Power | 70 | 80 | Two 100 kVA (480-208/120) |
| | Mech. Utilities | 150 | 175 | |

(1) Includes power supplies where applicable

(2) Assumes average power factor of .85.

Within the scope of the electrical utility system, the following miscellaneous services are included:

- Temporary construction power
- Emergency lighting in the tunnels and major buildings
- Area lighting at each ring entrance and interaction area
- Emergency power for sump pump and vacuum pumps during electrical outage periods
- Fire-alarm detectors for the support buildings where instruments, computers, and power supplies are housed
- 480 volt motor control centers for LCW pump motors and tunnel exhaust fan motors.

2. Cooling Water Systems and Piped Utilities

The PEP requirements for general mechanical conventional facilities design, construction and installation are outlined briefly below.

Heat Rejection to Cooling Water. Approximately 83% of the electrical input to the storage ring and interaction area detectors will be rejected to cooling water. Machine components will be cooled by closed-loop LCW systems which will in turn reject heat to cooling tower water systems. Heat loads will be as follows:

| | Load | MW Heat to Cooling Water |
|---|---|---|
| 1) | Magnets and Power Supplies | 5.5 |
| 2) | RF Power, Vacuum Chambers | 14.0 |
| 3) | Interaction Area Detectors and Power Supplies | 4.3 |
| 4) | House Power and Mechanical Utilities | 2.0 |
| | Total | 25.8 |

Primary Utility Loops. Buildings and tunnels will be served by a number of underground piped utilities. These lines will be looped and located within the ring circumference so that the outer edge of the piping is at least 20 m from the centerline of the tunnel. Primary connections to these pipe loops will be extended to or from the existing SLAC underground piped utility system. A diagram of the main loop is shown in Fig. 69.

Cooling Tower System. The SLAC research area is presently served by a cooling tower with four cells rated at 7.5 MW each. Projected SLAC research loads indicate that Cells No. 1 and No. 2 must remain committed to the SLAC research yard. Cell No. 3 will be reconnected to provide cooling tower water (CTW) for PEP. Cell No. 4 must be kept in service for present purposes, but is lightly loaded. Accelerator Cooling Tower No. 1202 located at Sector 23 can accommodate the PEP injection magnet system load and the Central Shop cooling tower can handle the house power load for auxiliary PEP buildings. The main PEP CTW loop capacity will be 24 MW. Two new PEP cooling tower cells rated at 7.5 MW each will be installed and a new CTW pump basin will be added with three pumps.

RF Cavity and Vacuum Chamber LCW Cooling Systems. The RF cavities and vacuum chambers are of aluminum and must be baked out. For economical considerations, heated water at $458^{\circ}K$ and 18 atm pressure should be used. A single portable heater will be used to heat the LCW at the mechanical utility pad at Interaction Regions 4, 8, and 12. The design input to the RF cavities is 9 MW and a maximum of 5.3 MW will be absorbed by stored beams and deposited in the vacuum cooling system via synchrotron radiation; therefore, heat rejection at the cavities will vary from 3.7 MW to about 8.0 MW depending on beam energy.

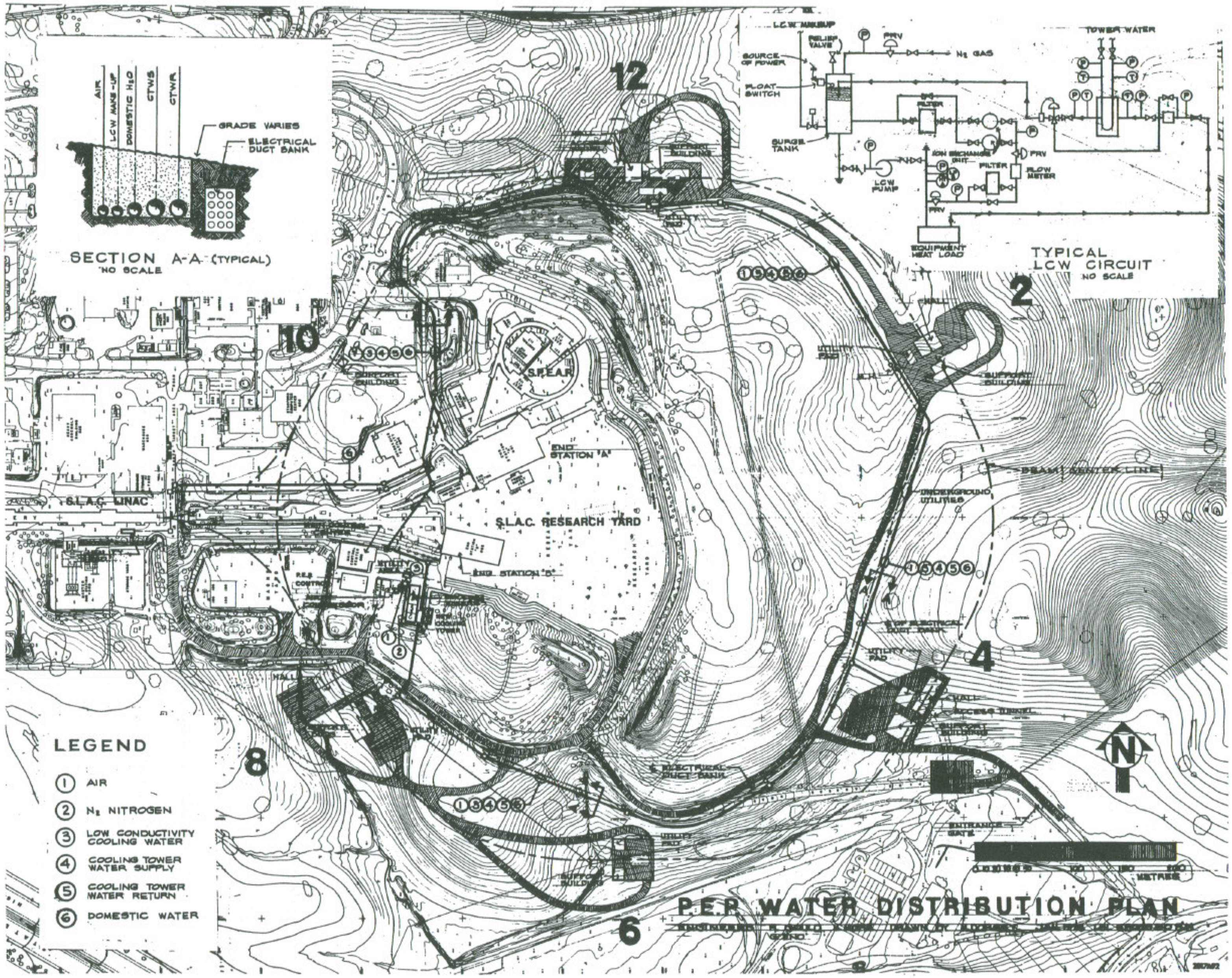


Fig. 69--Cooling tower water system.

Synchrotron radiation with a maximum heat flux of 1.06 $MW/m^2$ is deposited into and through the aluminum dividing wall between the vacuum wall and LCW cooling passages in the chamber. Since organic materials can plate out in aluminum LCW passages, the RF and vacuum chamber LCW distribution systems will be of stainless steel except for the aluminum vacuum chambers and masks.

Klystron galleries will be located at Regions 12, 4 and 8 around the ring. Cooling water for the RF cavities and vacuum chambers will be supplied from pumps and heat exchangers located near the RF housing as shown in Figs. 60, 62, and 64. The arrangement of the RF cavity and vacuum LCW cooling systems is shown in more detail in PEP Note 133.

Klystron and Ring Magnet LCW Cooling Systems. Klystron LCW cooling passages are of copper, ring bending magnet water-cooled coils are of aluminum and ring quadrupole water-cooled coils are of copper or aluminum. Most LCW piping will be of thinwall stainless steel.

Each klystron, during normal operation and assuming 66% efficiency, will reject 256 kW to LCW and generate 500 kW of RF power output. With no RF power output, all input to a klystron will be removed by its LCW system.

The required LCW supply pressure to main bending magnets and all other LCW-cooled in-ring magnets is 15 atm. The design load for in-ring magnets is 4500 kW and the maximum desirable LCW temperature rise is $20^{\circ}K$. The arrangements of these cooling systems are indicated in PEP Note 133.

Injection Magnet LCW Cooling Systems. The principal injection tunnel equipment to be cooled is the bending magnets, for which the anticipated heat load is 760 kW, and the LCW cooling system design parameters are similar to those for the ring bending magnets. LCW supply pressure will be 18 atm and temperature rise will be $20^{\circ}K$. One cooling system will be used and the heat exchanger and pump will be located at Sector 30 of the linac.

Interaction Area Detector LCW Cooling Systems. There are five major interaction area buildings; each may impose a heat load of up to 850 kW. The system will be designed for expansion to ~2500 kW when required. Optimum detector magnet design requires high LCW friction heat losses and optimum detector design requires spacial stability so that the LCW supply temperature can be controlled. Initially, one LCW system will be installed at Regions 12, 2, 4, 6 and 8. Pressure will be 25 atm and temperature rise through detector magnet coils will be held to $20^{\circ}$K.

Underground Piped Utilities. All underground piped utilities except CTW supply and return loops are extended from existing SLAC systems. CTW supply and return loop pipes will be 10 atm pressure class 150 asbestos cement. A LCW makeup pipe loop will run from the existing SLAC-research-area LCW storage-tank system with a distribution pressure of 7 atm. Domestic water, distributed throughout SLAC at 5 - 6 atm pressure, is used for fire protection and other domestic purposes. It will be run through 10 atm-pressure rated asbestos cement piping under grade around the inside of the PEP ring tunnel.

A medium-pressure nitrogen gas loop will be provided with valved branch lines extending to various PEP loads. The nitrogen loop will be run in the PEP ring tunnels and will be used primarily for operating the pneumatically actuated fast valves of the vacuum system.

The existing SLAC compressed air system distributes clean, dry compressed air at 7 atm pressure. The compressed air loop for PEP will be run through asbestos cement pipe and will be extended to all LCW cooling systems, the PEP cooling tower and all PEP buildings for use in control systems and for other purposes.

A natural gas loop made of two-inch wrapped all-welded steel, extended to the LCW heater stations and to each of the five interaction buildings will be provided.

3. Fire Protection Systems

All areas are classified as Ordinary Hazard, Group I. The sprinkler systems are designed for a coverage of 0.15 gpm/sq ft. The ring is to be divided into twelve zones, each zone with its separate water supply. Six of these zones will supply water to the center of the curved sections of the tunnel. The remaining six will supply water to the interaction areas.

The tunnel sections will be protected by dry-pipe, air-supervised, fusible-link head pre-action sprinkler systems. Ionization type smoke detectors will both alarm and actuate the supply valves to the systems and a manual override will prevent actuation of the supply valves if desired during working hours.

Because of the height of the interaction areas, these will be protected by open head, deluge systems. Both ionization-type smoke detectors and rate-of-rise heat detectors will be used. The smoke detectors will alarm only. The smoke detectors and the heat detectors are interlocked so that signals from both will be required to actuate the deluge valves. A manual override is also provided for these systems.

Surface buildings will be protected by dry-pipe, air-supervised, fusible link head pre-action sprinkler systems. Both ionization-type smoke detectors and rate-of-rise/fixed-temperature detectors will be used. The smoke detectors will alarm only. Signals from both the smoke detectors and the heat detectors will be required to actuate the supply valves.

Fire hydrants capable of delivering 1500 gpm at 20 psi residual pressure will be installed on either side of the interaction areas.

The source of the water for fire protection will be the 10 in. diameter cement-asbestos domestic water pipe which will be installed circumferentially inner-annular to the ring. Domestic services will be connected on the water-main side of the automatic fire protection supply valves.

4. Ventilation

Each curved section of the tunnel will have an exhaust fan located at the midpoint in the ceiling. These fans will provide five air changes per hour and maintain a slightly negative pressure within the tunnel. The air velocity in the tunnel will be very low. In accordance with the recommendations of fire protection engineers, these systems will be maintained in the "on" position during fires to remove smoke, thus assisting fire fighters and minimizing smoke damage to equipment. The air intakes at each end of the curved sections will be provided with smoke detectors which will shut off the fans and close the exhaust duct in order to prevent the drawing of smoke into the tunnels from fires on the outside.

The interaction areas will be provided with both supply and exhaust fans maintaining a slightly positive pressure in the area. The exhaust fans will draw from floor levels in order to remove any heavier-than-air gases which may be used in experiments. Local space heating will be provided as needed.

The surface building will be provided with ventilation and/or space heating depending upon the character of the equipment contained within the building.