EUROPEAN ORGANIZATION FOR NUCLEAR RESEARCH

CERN/MPS/LINP 73-1

4th October 1973

PROJECT STUDY

FOR A NEW 50 MEV LINEAR ACCELERATOR

FOR THE C.P.S.

by

The New Linac Working Group

Editor : D.J. Warner

PREFACE

In April 1973 the PS Department Management decided to set up a Working Group assigned to working out and describing the design of a new Linac as a first stage of the CERN accelerator complex. Members of this Working Group have met in many informal discussions and plenary sessions since May 3, and produced a draft report by mid September. The draft was critically reviewed in a seminar held in Leysin from September 26 to 28, 1973 to which a number of external consultants were invited.

We are grateful for the many suggestions we have received from our consultants as well as for the contributions which many members of MPS Division have made during the past months.

G. Plass
Chairman of the Working Party

October 4, 1973

Members of the Working Group

D. Bloess
E. Boltezar
M. Georgijevic
P. Grand (on leave from BNL)
H. Haseroth
W. Pirkl
G. Plass
C.E. Rufer
T. Sherwood
P.H. Standley
U. Tallgren
C.S. Taylor
P. Têtu
L. Turner
D.J. Warner
M. Weiss

Invited participants of the Seminar

B. Bru
J. Gareyte
W. Hardt
J. Huguenin
P. Lapostolle (C.N.E.T.)
B.W. Montague
G.L. Munday
G. Nassibian
C. Planner (R.H.E.L.)
J. Stovall (L.A.S.L.)
N. West (R.H.E.L.)

Contents

1. Introduction

The PS Linac is the vital first stage of a large accelerator complex comprising the CPS, the Booster, the ISR and soon the SPS. During the last 15 years the present Linac has been developed to meet the increasing demands made upon it and has now reached a stage of performance far beyond that originally envisaged in its design.

Future demands on the Linac are expected to become even more stringent in terms both of reliability and performance, and will continue for a period of at least 20 years. The present machine has reached the practical limit of routine development; to maintain the performance at the increasing level demanded by the new CERN facilities will require either a major reconstruction or a replacement of the present Linac.

A major reconstruction of the existing Linac is excluded because of the long shut-down time required and the physical limitations imposed by the present layout. Furthermore it is unlikely that reconstruction would be much less expensive than a complete replacement by a new machine. Consequently, we have been led to recommend the construction of a new Linac .

This report discusses in more detail the above considerations and describes the proposed design and construction project. The construction period is estimated to be 4 years, the material budget 21.3 Mfr. and the manpower required 150 man-years.

2. Review of the CPS Linac

The CPS was originally conceived as a cascade of three accelerators : a 500 keV Cockroft-Walton pre-accelerator, a linear accelerator of 50 MeV and the proton synchrotron with a top momentum of 28 GeV/c. A fourth machine, the 800 MeV Booster, has recently been added to increase the intensity of the CPS by a factor of 10.

The present Linac was ordered in 1954, and was based on a design which had been developed for a similar machine by the Harwell (now Rutherford) Laboratory. The essential requirement for the machine was a proton pulse of a few mA at 50 MeV energy and about 10 µsec duration. This accelerator was brought into operation in 1958/59 and its continued upgrading during the following years allowed the output current of the CPS to be increased by nearly two orders of magnitude.

Beam transfer from the Linac to the Synchrotron was initially based upon the technique of "single-turn" injection and hence the accent was first put on the increase of intensity at constant pulse length. The development was essentially centred around the construction of a duo-plasmatron ion source connected to a high gradient accelerating column. This source now yields a current of about 500 mA, of which 50 mA to 80 mA is accelerated in normal operation to 50 MeV.

The Booster, based on "multi-turn" injection, requires substantially longer pulses from the Linac. A pulse of 100 mA and duration of 100 µs (about 15 turns) was specified during which time the longitudinal and transverse beam emittances must remain within certain tolerances.

In an effort to meet these new requirements the Linac was further uprated by :

a) the addition of RF power amplifiers, increasing the available power by a factor of two;

b) the addition of high voltage compensation to the preaccelerator;

c) the increase of power to the focusing quadrupoles in tank 1 which, in spite of extra cooling, brought these quadrupoles to the limit of their thermal dissipation capacity and voltage break-down.

These major modifications pushing some components to their limit have enabled us to operate stably with a beam of 50 mA and a pulse length of 80 μsec (see table 1).

3. Justification for a New Linac

The performance of the CPS Linac has been upgraded in the past 12 years by three orders of magnitude in the amount of charge accelerated. However, it has been clear since the beginning of the CPS Improvement Programme, that a number of major components would have to be rebuilt. Stretching the performance of the existing components even further was bound to lead to reliability problems, yet the tight specifications of the operation with the Booster must be achieved reliably and with a certain safety margin. Also it became clear that the Linac would have to continue to operate during the increased life expectancy of the PS complex; this was implied in launching the Improvement Programme and in the use of the PS as an injector for the ISR. The decision to use the CPS as an injector for the SPS emphasizes this fact even more.

Among the items considered to upgrade the Linac further were the following:

- a project for replacing the tanks, allowing stronger focusing and the possible increase in injection energy 1);

- an ion pump system replacing the present ageing diffusion pumps and associated refrigeration system, to improve reliability and to reduce the maintenance cost and effort. This can only be done in conjunction with the replacement of the accelerator tanks;

- introduction of computer control 2);

- a complete rebuild of the RF system and the installation of the RF amplifiers outside the radiation area. Operational experience has shown that, to provide independent adjustment of RF level and phase of each of the three tanks, replacement of the present common driver amplifier by individual driver chains on each of the six power stages, and the introduction of fast feedback on each chain, are essential.

In addition to these points, one finds in the linear accelerators built in the past five years many features which must be incorporated in any new or rebuilt machine, for instance :

- the sensitivity of the accelerating structure to errors in dimensions and to beam loading effects is reduced by the introduction of coupling devices ("multi-stem couplers" or "post couplers") which improve the flow of power along the tank. This reduces transient level differences along the structure and allows sounder operation of the beam loading compensation circuits;

- the pre-accelerator energy is 750 keV and a drift space between accelerator and Linac tank 1, of between 4 and 7 m length (less than 2 m in the CPS Linac) is provided in order to allow space for beam diagnosis and proper transverse and longitudinal matching of the beam into the Linac;

- all supplies and ancillary equipment are placed in an equipment gallery, separate from the accelerator tunnel, and are thus accessible during operation, bringing about obvious advantages for surveillance and maintenance.

Replacing the present Linac by a new one in the present location will have the following consequences:

a) The injection energy will be limited to the existing 500 keV and the diagnostic and matching equipment will remain limited essentially to the present layout.

b) The RF system will be at a considerable distance from the tanks which will impair the performance of the beam loading compensation feedback system.

c) The shut-down required to dismantle the existing Linac, to install a new one and to commission it will stop the operation of the whole accelerator complex for an estimated 9 months or more. (Partial rebuilding, going as far as replacing successively all its essential components, has been discussed extensively. Though possible in isolation, this procedure will create serious problems of scheduling in the context of the whole complex where the coordination of the plans and needs of SPS, ISR, 25 GeV physics and CPS is already a complicated task. At each major step, the risk of unscheduled down-time, due to start-up problems, would be added. Furthermore, even fewer modifications could be included in a piecemeal rebuild, since the design parameters would basically be fixed by the present machine.

The economies achieved by installing the new Linac in the existing building compared to installing a completely new Linac in a new location will at best be the civil engineering expense, i.e. between 20 and 25 percent of the total cost. These savings would be reduced by the need of increased manpower to cope with a very tight installation schedule. Clearly, no stand-by would be available during the running-in period, whereas the present Linac will be available during all the early operation of the new machine in a separate building.

It is therefore recommended that a new Linac be built in a new location.

The construction of the new 50 MeV Linac will incorporate all the features listed above : its design is described in the following chapters.

The objective of the project is to achieve a reliable machine producing beams of predictable and hence reproducible quality and with parameters which can be selected within ranges covering the performance potentialities of the subsequent accelerators.

Since it is not intended to keep the present Linac alive for more than a few months overlap a significant reduction of maintenance effort can be expected due to the modern techniques (e.g. vacuum system) incorporated. Typically, a reduction by 25%, i.e. 9 or 10 people, would pay for the building cost within 10 years of operation.

TABLE 1

Main Performance Parameters

of the Present and the New Linac

	PRESENT LINAC OPERATIONAL VALUES		CPS IMPROVEMT. PROGR. SPEC'N (1967)	NEW SPECIFICATION	
	1960	1973			
current	$\sim$ 10 mA	50 mA	100 mA	50-150 mA	
pulse duration	10 µs	80 µs	100 µs	200- 70 µs	
max. energy spread	*)	± 90 keV	± 150 keV	± 150 keV	for 100 mA
emittance (at 50 MeV)	*)	$\sim$ 20 πmm mrad	< 30 πmm mrad	< 25 πmm mrad	
repetition rate	1 pps	1 pps	1.7 pps	2 pps	

*) No comparable values available.

4. General Description of the New Linac

4.1 Outline of the Project

The Booster is now becoming available as a machine specifically designed for acceleration from 50 MeV to 800 MeV and there is no incentive at present to change the final energy of the Linac. The new Linac will therefore be designed for 50 MeV output energy; other main performance parameters are included in Table 1.

As a major feature of the new machine, we aim to have a large freedom in the choice of operating conditions and the flexibility required to modify them rapidly. The site is near the present Linac with the axis of the two machines nearly parallel (see Fig. 1). With the requirement to inject both into the PS and into the Booster, there was in fact little choice in the location.

In the interests of reliability and continuity of operation, the machine is conceived essentially as a "proton factory"; though provision is made for the development of certain options (see Chap. 4.3), the acceleration of heavier ions is not considered at present. (The old Linac building would become available for this type of development).

The design of the new Linac leans on the experience gained with existing machines and, in addition, is based on methods and computations developed over the past five years.

Beam dynamics studies carried out at CERN and other laboratories show the importance of many factors which could cause discontinuities and adversely affect the Linac performance; this has been taken into account in the choice of parameters. In particular, by increasing the preaccelerator energy up to 750 keV we align ourselves with the practice of most other proton Linac laboratories.

Concerning mechanical design, sets of drawings are available from some of the American Linacs, the new NIMROD and SATURNE injectors, and from our 3 MeV experimental accelerator and it is hoped to use some of the design principles directly.

There is a continuous exchange of views on controls inside the division and the developments for the SPS project are followed closely. It is intended to use the CAMAC system which is finding general acceptance.

A collaborative effort is under way with Rutherford Laboratory on matters concerning power amplifier design and tube development.

A study programme giving a continuous check on the design principles will accompany the construction programme.

4.2 Design Parameters

In Table 2 the essential design parameters are summarized.

TABLE 2

		Comments
Particles	Protons	
Repetition Rate	2 pps max.	
Preaccelerator		Ch. 5.1
Current	up to 400 mA	
Source	duoplasmatron	
Energy	0.75 MeV	Ch. 5.1.1
H.T. Generator	cascade set	
voltage	900 kV	
stability	$\pm 5 \cdot 10^{-4}$	
current	5 mA	
Acceleration column	high gradient, double gap configuration	

TABLE 2 (Cont.)

750 keV beam transfer		Ch. 5.2
Transverse matching		
number of quadrupoles	16	
max. gradient	40 T/m	
Longitudinal matching		
number of bunchers	2 at 202.5 MHz 1 at 405 MHz	Ch. 5.2
Linear Accelerator		Ch. 5.3
Current	operating range $50 \leq i \leq 150$ mA	max. charge per pulse : 16 µC (10^{14}p)
Pulse length	operating range $200\ \mu s \geq t \geq 70\ \mu s$	
Beam quality at 50 MeV		
emittance	$\varepsilon \leq 25\ \pi$ mm mrad	these are limits for 100 mA, see p. 11 for other currents
energy spread after debunching	$\Delta W < \pm 150$ keV	
Energy	50 MeV	To match existing injection apparatus of Booster
Structure		
type	Alvarez stabilized by post couplers	
number of tanks	3	
tank frequency	202.5 MHz	same as present Linac
acceleration rate	varying between 1 MeV/m and 1.55 MV/m within tank 1, constant in tanks 2 and 3	
synchronous phase	at input of tank 1 : $26^\circ < \lvert\phi_s\rvert < 40^\circ$	
	at output of tank 1 : $20^\circ < \lvert\phi_s\rvert < 30^\circ$	
	in tanks 2 and 3 : $20^\circ < \lvert\phi_s\rvert < 30^\circ$	constant ϕ_s within each tank
number of cells	∿ 124	table 3
total length	33 m	

TABLE 2 (Cont.)

Quadrupole Focusing	N = 1 (FD) configuration	
max. gradient	100 T/m	
RF System	5 amplifier chains	Ch. 5.5
peak output power	2.6 MW per chain	
peak supply power	50 kW per chain	
50 MeV Beam Transfer		Ch. 5.4
Bending magnets		
BH1	$\pm$ 60 mrad (pulsed)	
BH2	300 mrad (DC)	
BH3 (IBH1)	$\left.\begin{array}{r}385\text{ mrad}\\ 85\text{ mrad}\end{array}\right\}$ pulsed	
stability	$\pm 2 \cdot 10^{-4}$	
Transverse matching :		
number of quad.	10	
max. gradient	1.2 T/m	
Longitudinal Matching :		
number of debunchers	2 at 202.5 MHz 1 at 405 MHz	

Beam quality criteria used for multiturn injection calculations in the Booster [3)] give an useful rule of thumb for expected optimum emittance and energy spread with variation in proton current, I_o (over the range $50 < I_o < 150$ mA quoted in Table 2). One can specify a proton beam by I_o and ε_o assuming that current I contained in emittance ε is $I = I_o \left[1 - \exp\left(-\varepsilon/\ \varepsilon_o\right)\right]$. For optimum 50 MeV beams :

$$\frac{I_o}{\varepsilon_o} > 12 \ \frac{\text{mA}}{\pi \text{ mm mrad}}$$

$$\Delta W \simeq \pm \left[(50)^2 + (1.5\ I_o)^2\right]^{\frac{1}{2}} \text{ keV}$$

where the space charge blow-up term and assumed energy jitter are combined as 1.5 I_o, with I_o in mA.

As the requirements of future operation are not known now and must even be expected to change in time, it will be preferable to accelerate only the number of protons required, rather than to accelerate and dump them on an aperture restriction. With pulsed power supplies, it is reasonable to aim for interpulse flexibility but with, for example, changes in ion source and mechanical positions, timescales of minutes are more normal. The Booster might, in future, require beam qualities below the optimum as defined above, so one expects to develop the debuncher method already used for ΔW variation and also to study methods of reducing I_o/ε_o (including the standard "sieve" method).

We believe that the study programme will permit us to store in the computer a sufficient number of parameters so that changes of operating conditions will be reasonably fast.

4.3 Possible Options

4.3.1 Acceleration of Negative Hydrogen Ions

In several laboratories in the USA, injector systems for synchrotrons based on the acceleration of H^- and inflection by charge conversion in a stripper foil are being developed. The essential interest of this technique resides in the charge exchange inflection being a non-Liouvillian process; it is therefore expected that a high proton density could be accumulated during many turns in a restricted portion of the phase-space of the synchrotron. From the present research H^- source currents between 10 and 20 mA are the maximum expected. The beam loading problems in the Linac would be alleviated but the pulse duration would have to be increased accordingly to about 1 msec.

Adequate H^- currents have not yet been achieved with the sources under investigation (except for some Russian work not yet verified) and it is not known to what extent an increased density would be preserved during acceleration in the synchrotrons. Hence there is at present no definite incentive to duplicate the development programme of H^- sources under way elsewhere. It is clear, on the other hand, that the option to employ such a system when necessary, must be kept open on a new Linac.

For the Linac itself, no modifications other than the exchange of the ion source and reversal of preaccelerator polarity, and the extension of RF and quadrupole pulse duration are necessary. These will be kept in mind when designing the respective components and the required space will be provided in the preaccelerator area and the equipment gallery.

4.3.2 Increase of Energy

The accelerator tunnel being a few metres longer than required for a 50 MeV Linac, we have a reserve at hand to increase the energy by about 10 MeV without giving up any of the essential features of the project. A possible use of about 58.5 MeV final energy would be in a scheme of transferring the bunches formed in the Linac in matched RF buckets through all the synchrotrons right into storage rings added to the SPS, thus hopefully preserving longitudinal phase-space density. (The Booster and PS RF systems would of course have to be replaced by others working at the appropriate harmonic numbers).

If for any other reasons, the need for higher final energy should arise, another 20 MeV or so could be made available by suppressing the new measuring lines. (The need for the latter will be less urgent after a few years of operation since there is a second set-up existing further downstream in the transfer line towards the Booster.)

4.4 Study Programme

Although beam dynamics computations have to some extent already been compared with measurements on most contemporary machines, further experimental verification is needed. In particular, we want to acquire detailed information about performance of the new Linac and its components as a function of a comprehensive set of parameters. A study programme is therefore planned to accompany the whole duration of the project.

In the first stages of the study programme 4) it is intended to use the existing 3 MeV experimental Linac for proton source studies and for the verification of computations at 520 keV, of the bunching/matching system under space charge conditions. As a final test of the design a further series of measurements will be carried out on the new preaccelerator (750 keV). The final studies at 10 and 50 MeV levels will be concerned with the parameters of the Linac itself.

In view of the large number of parameters involved in these studies, computer acquisition of the results is essential. Hardware and software for data acquisition and treatment on one of the existing PDP 11/45 systems will hence be the first parts to be provided for the control system of the new Linac.

5. Subsystems

5.1 Preaccelerator

5.1.1 Preaccelerator Energy

The essential parameters of the preaccelerator are current, pulse duration and energy. Both current and pulse duration are determined by the requirements of the circular accelerator accepting the 50 MeV Linac beam.

There is more freedom for the choice of the preaccelerator energy which could be anything between 500 and 800 keV, higher voltages leading into a different technology. We are,at the CPS,in the particular situation of having a 520 keV preaccelerator,which has led to experience being built up in handling this voltage. On the other hand, our preaccelerator energy is the lowest of any working proton Linac and the majority, including the recently built machines, are working at the 750 keV level. Designs for this energy are well developed and components and know-how are available,though the cost of the H.V. generator and Faraday cage will be higher.

The pros and cons of two alternatives - to stay at 520 keV or to follow current practice by changing to 750 keV - have therefore been reviewed in some detail$^{5)}$. The conclusion is that the advantages to be gained with a 750 keV system concerning :

a) flexibility in the Linac low energy end focusing;
b) bunching efficiency;
c) bunching voltages and corresponding electric fields;
d) space charge influences;
e) space considerations in the bunching region;
f) energy transfer between phase planes in the Linac;
g) reduction of unwanted effects e.g. neutralization

override the straightforward advantages of a 520 keV injection, viz. :

a) proven 520 keV design;
b) available test facilities for 520 keV;
c) smaller building;
d) smaller total cost and effort (price difference : 0.4 to 0.5 MSF).

Quite definitely, optimum beam dynamics and the flexibility to select the Linac parameters giving the desired 50 MeV beam quality should be prevailing goals. Therefore this study and the cost estimate include a 750 keV preaccelerator. A possible layout for a 750 keV Faraday cage is shown in Fig.2 .

5.1.2 Column

The accelerating column is probably the most critical element inside the Faraday cage and the present column has to be modified to deal with about 50% increase in voltage. Several columns in other laboratories are actually working at this level and operation is normally without problems. Nevertheless the high-voltage behaviour is still not very well understood and there remains essentially a field of "trial and error". Keeping this in mind, it seems wise to copy an existing column without too many modifications.

Here are three major points :

a) The beam optics and the number of gaps: the necessary focusing elements may be distributed (Pierce) or concentrated. At the moment there is no clear indication that a multigap Pierce accelerating structure has advantages compared to the CERN double gap column6).

b) The gradient on the accelerating structure: the proper materials are known7) and there are fairly well established upper limits8).

c) The allowable gradient on the column wall outside and inside the vacuum : this will determine the length of the column and the insulating strength required (using air, SF_6, etc.).

In view of the limited time scale we will modify the existing column to hold 750 kV. The main problem is the increased gradient on the outside of the column. There are two solutions possible which do not involve a large redesign.

One possibility would be to put our column into sulphur hexafluoride. The appearance will then be similar to the columns at NAL and LAMPF but with a large safety factor due to the lower voltage gradient on the outside of the column. The cylinder containing the SF_6 will be considerably longer than the column and will be surrounded by corona rings to guarantee a constant gradient in the air. The mechanical design effort required for this solution is not negligible.

The other possibility would be to go from our present 14 section column to 18 sections9,10) increasing the voltage holding capability up to 850 kV. Only a few modifications would be necessary. The disadvantages in this case would be : decrease in the safety factor for the H.T. behaviour and the obligation to keep the present expensive resistors along the column. The resistance should be reduced to obtain a more rigid potential distribution along the column.

The inside of our column probably does not need any major modifications. The diameter of the anode could be slightly decreased if necessary by making a small modification to the source. In addition, some stainless steel parts ought to be replaced by titanium and a few shielding rings will need a larger radius.

5.1.3. The High-Voltage Supply and Circuit

The high-voltage supply is obviously much less of a problem because it can be bought as an expensive and clumsy but fairly reliable arrangement. Smaller and more elegant supplies have been built at different places (e.g.11,12) but no solution is yet found that gives the same operational safety as the commercially available series-fed Cockroft Walton Generators in open construction.

Possible improvements on the latter concern transistorizing both the regulation and the high power stages.

The H.T. will be connected to the load (electronic platform, accelerating column and measuring resistor) through a protective resistor. Probably a filter capacitor will be added in order to protect the generator against fast transients,assuring at the same time maximum flexibility for any future beam pulse requirements. The fast compensation will be made via a separate condenser,allowing for a damping resistor between it and the load. There are no strong reasons to keep the end of the accelerating column physically or electrically away from the electronic platform.

For powering the platform, preference would be given to an insulating transformer. Contacts with the industry seem to be promising13).

5.1.4. Compensation Circuit

A similar system14) to that on the present Linac may be used. The electronics will be updated by introducing transistors and feeding back more parameters (beam current, dV/dt etc.) to obtain a better stabilization15).

At present commercially provided units on other accelerators are not satisfactory and they are either not in use or have been considerably modified.

The reason for a separate condenser rather than using the H.T. set for compensation, is the better protection of the Cockroft Walton against excessive currents and the gain of flexibility for different beam pulses (current and/or pulse length).

5.1.5. Ion Source

There are at the moment no strong reasons for choosing another design. The CERN source, working in the present Linac, compares rather well[16)] with sources elsewhere. There are no indications that major changes are needed in the mechanical assembly. Improvements are certainly desirable for reducing the hydrogen flow and increasing the stability of the output current, especially at the beginning of the pulse. The latter seems to be possible by introducing another electrode[17)] and by defining the snout potential in a different way - very likely in a more rigid way. How easy it is to reduce the hydrogen flow by making only small modifications, is difficult to estimate. However, proper stabilization of the H_2 pressure will be provided, to guarantee a better long term stability without frequent readjustments.

5.1.6. Controls

A large amount of information transfer from the H.T. terminals to ground potential has to be provided, since this will be the only part of the new Linac containing vital electronics, which will be inaccessible while the machine is running.

The system on the present Linac, sending only a few trigger pulses or pulse trains, will be inadequate in the future. The basic principle (photo-link) could be kept, but digitized information as well as analogue signals have to be transmitted for the main parameters of the ion-source.

5.2 0.75 MeV Beam Transport and Matching

5.2.1 Definition of the Problem

The low energy beam transport system (LEBT) is intended to transport the beam coming from the preaccelerator, to bunch it and match it to the Linac acceptance, defined in a six-dimensional phase space. The LEBT has to operate correctly over a reasonable range of input conditions (ion source settings) and output conditions (Linac operating settings). The requirements can be summarized as follows :

a) transport and correct matching of preaccelerator beams to result in Linac beams in the range 0 to 150 mA;

b) high bunching efficiency in order that the non-trapped particles do not disturb the beam dynamics in the low energy part of the Linac; the ratio of trapped to lost particles should be bigger than two;

c) possibility of changing the beam intensity rapidly, keeping either the beam emittance roughly constant or varying it;

d) small transverse emittance blow-up;

e) beam measuring apparatus to facilitate and control the settings of parameters;

f) inclusion of some empty drift space for a possible later insertion of apparatus.

5.2.2. Specification of the Beam

The layout and settings of the LEBT depend on the characteristics of the preaccelerator beam. The beam has to be described in a way which is convenient and sufficiently accurate for a design optimization. The best method is to specify the beam by its intensity and rms values of phase space coordinates. The rms values are more significant than the boundary ones, because they contain information about the density distribution.

The preaccelerator beam is a "continuous" beam; its transverse density distribution is supposed to be of the ellipsoïdal type, i.e. the equidensity curves are approximately homothetic ellipses. The evolution of rms values depends in such cases, practically on the linear component of space charge forces 18) only . This property permits one to replace in calculations the real beam by an uniform equivalent beam, provided the latter is given the same rms values; linear optimization routines can be used for design purposes. It is the equivalent beam which is quoted in this paper.

As far as the vacuum chamber and quadrupole apertures are concerned, they are, of course, chosen corresponding to the size of the real beam.

5.2.3. Design Principles

The Linac acceptance to which the input beam has to be matched is defined, in its linearized form, as a six-dimensional hyperellipsoid; the projections in each of the phase planes are ellipses. The acceptance is not only a function of Linac parameters but depends also on the intensity of the input beam 19,20). This is particularly true for the longitudinal phase plane, where the space charge effect cannot be compensated by an increased quadrupole focusing, as is the case transversely. The longgitudinal acceptance roughly maintains its extension in RF phase, but the permissible energy spread is reduced with space charge as shown by approximate curves on Fig. 3 .

The choice of the bunching system is an essential feature of the design of the LEBT. This problem has already been studied 21,22) and a system of two bunchers, the second one working on the second harmonic of the RF frequency, chosen. Such a double drift harmonic buncher system (DDHB) has to give :

a) high bunching efficiencies (of the order of 70% compared to ∿ 50% with one buncher) and

b) better filling of the longitudinal acceptance.

In order to keep a high efficiency of the DDHB over a large range of beam intensities, a third buncher is added close to the Linac to correct for space charge influences. This buncher, in fact, is not a buncher in the usual sense of the word, but acts more as a longitudinal lens, giving to the longitudinal beam emittance the correct axis ratio. It is called an energy-spread corrector (EC).

The design of the LEBT is arrived at by successive approximations, the first solution being obtained by neglecting the space charge. The design procedure can be summarized as follows :

a) Preliminary design with I = 0 : one calculates the parameters of the DDHB system with the condition that one obtains the highest bunching efficiency and matches the beam to the longitudinal Linac acceptance. Then, one searches for matching solutions in the six-dimensional phase space, determining the strengths and positions of quadrupoles and modifying, if necessary, the bunching parameters.

b) Design optimization with space charge : the matching obtained above is optimized for different current levels and each solution checked by analysing the beam characteristics with a multiparticle program. Nonlinear phenomena, such as emittance blow-ups are revealed and adequate measures taken.

c) Final check of the design : the layout of the LEBT, optimized for a nominal current, is checked to see if it works in a satisfactory way in the whole interesting range of input conditions, output conditions and beam intensities.

An important constraint on the design of the LEBT is the requirement for minimum emittance blow-up. The emittance is increased by non linear space charge phenomena and by the RF field in the bunchers. Fig.4 shows the transverse emittance growth in bunchers, as a function of the beam dimensions and bunching parameters. A high bunching efficiency is obtained only with limited beam sizes in the bunchers.

5.2.4. Layout of the Low Energy Beam Transport System

The LEBT can be divided into four logical sections :

1) Measuring section, just after the DC accelerating column, including an intensity and an emittance measuring device. A free space of about 0.5 m is reserved for a possible later insertion of apparatus (eg. beam chopper).

2) Beam limiting section, having a system of two four-jaw apertures to limit the beam proportionally in angle and diameter; it includes also a system of sieves of different transparency, to lower the beam density uniformly over the cross-section. The free space between the four-jaw apertures is about 0.7 m; the junction with a possible future H^- beam line would be made here.

3) Transition section, to diminish the size of the beam; small emittance blow-ups and good bunching efficiencies are obtained with beam sizes $\leq$ 10 mm in the bunchers.

4) Bunching and matching section (the most important one) which determines the characteristics of the beam to be injected and accelerated in the Linac.

Fig. 5 shows the layout of the LEBT, with indicated envelopes for a preaccelerator current of 200 mA. The current trapped in the Linac is 140 mA (a multiparticle program result), practically the maximum required. Fig.6 gives a table where the input and output conditions, as well as the LEBT parameters (for 200 mA) are summarized. Fig.7 shows the energy modulation curve of the DDHB system. Figs 8a and 8b are outputs of the multiparticle program, showing the longitudinal beam emittances after the DDHB system and at the Linac input, respectively. The density distribution in the emittances is quite visible. The dotted line in Fig. 8b represents the Linac longitudinal acceptance; it is smaller than the emittance because the latter has grown in the course of transport, due to the non-linear space charge action*). Nevertheless, the inclination and the shape of the emittance are satisfactory.

As far as the mechanical engineering is concerned, the bunching and matching section causes some problems because of much apparatus installed in a rather restricted area. A solution found in the case of the energy spread corrector is to incorporate it in the front cover of the first Linac tank 23).

5.2.5. Tolerances

The tolerances imposed on quadrupole strengths in the LEBT are not severe : errors in integrated gradients of a few ‰ are tolerated 24).

The tolerance imposed on the bunchers concerns mostly their phase : the phase stability should be of the order of 1°.

Another factor which influences the bunching efficiency is the stability of the H.T. If the H.T. varies, the mean beam velocity will vary and cause the bunches to arrive with a wrong RF phase at the Linac input. The variation in HT which causes a phase error of 1°. is

$\frac{dU}{U} \underset{\sim}{\sim} \pm 0.04\ \%$, which is a rather severe requirement.

---

*) The design optimisation programs will be modified to take into account the inevitable beam emittance blow-ups.

5.2.6. Operation - Beam Measuring, Limiting and Steering Devices

It is intended to operate the LEBT with settings derived by the computer as a function of input beam characteristics and Linac operating conditions. One must therefore be able to :

a) measure the input (preaccelerator) beam ;
b) control the settings by measuring the output beam.

The input beam is measured by a beam transformer and an emittance measuring device placed in the measuring section (see Fig.5). A second beam transformer and emittance measuring device are placed after the beam limiting section to control the beam limitations. Finally, a third transformer and emittance device are put close to the Linac to measure the characteristics of the input Linac beam. One also expects to check the beam bunching by measuring the longitudinal bunch density, either by a strip-line probe[25], or by a pick-up station[26] introduced in the gap of the third buncher EC (which has then, of course, to be switched off).

The beam current is varied rapidly or adjusted to a particular intensity either by beam limiting apertures or by sieves of various transparency. The apertures affect both the beam density and emittance, whilst the sieves lower only the density.

Beam steering magnets are placed before the bunching section in order to have the beam centred on the axis of the bunchers.

All the above mentioned devices are shown in Fig.5.

5.3 Linac

In this section a summary is given of a proposed design of the Alvarez Linac with special emphasis on some methods and features which are novel or critical. Already several preliminary design options have been taken on input proton energy, output energy, accelerating rate and section lengths, to enable us to describe a feasible Linac. In fact, for the final design, recent studies indicate a lower output energy of tank 1 than the 10 MeV assumed here. Where possible we present evidence favouring particular solutions and design techniques. As standards of comparison, the designs of the most recent American Linacs [*], and the 70 MeV RHEL injector have been invaluable, but no real technical or economic advantages could be found in merely adapting their complete designs to the different requirements of CERN re output energy, pulse rate and r.f. power modules.

5.3.1 Linac Dynamics

A qualitative approach is used here to discuss the selection of operating parameters, especially at injection. Linearised equations of the type[19].

$$\ddot{x} + \overline{\Omega^2}\, x = 0$$

can be used to describe the transverse or longitudinal oscillations in the Linac with $\overline{\Omega^2}$ the smoothed value of restoring force over a complete focusing period. The acceptance (Area/π) is given by

$$A_x = (\overline{\Omega^2})^{\frac{1}{2}}\, x^2_{max}$$

In the transverse case one can decompose $\overline{\Omega^2_\beta}$ into the quadrupole focusing effect, the r.f. defocusing and the space charge defocusing and similarly in the longitudinal plane $\overline{\Omega^2_{so}}$ consists of an r.f. focusing term and a

---

[*] The "state of the art" at the time the designs of the NAL, BNL and LAMPF Linacs were frozen is given in reference[27] with design details published at the specialist conferences[28,29,30].

longitudinal space charge term. One can vary the acceptances via the quadrupole strength and the accelerating field level but the results for the transverse and longitudinal planes are coupled especially when space charge terms are important.

Qualitatively it is the $\dot{x}|_{max}$ dimension of the acceptance area which is reduced by the space charge effect (i.e. the ΔW extension in the longitudinal, $\Delta W - \Delta\Phi$ plane) and it is these modified acceptances which represent the boundary conditions to be met by the beam transport before the Linac. The choice of the Linac synchronous phase (Φ_s), accelerating rate ($\frac{dW}{dz}$) and quadrupole focusing strength at injection must then satisfy constraints dictated by :

(i) The obtainable bunch width, $\Delta\Phi_{min} \simeq 50^o$ so that $|\Phi_s| > 25^o$ 22).

(ii) Sensitivity of required focusing to beam current 19) and

(iii) Energy transfer between phase planes 31)

It has been suggested 32, 33) that for the phase law and final energy of the first accelerating section one can take as lower limits of Φ_s, those values just necessary to counteract the longitudinal space charge forces due to a 150 mA proton beam. A more thorough computational and experimental study will be made along these lines ; meanwhile it is assumed that the Linac input region design will allow sufficient variation in Φ_s and quadrupole settings to handle a wide range of beam currents.

5.3.2. Starting Conditions for the Structure Design

The preliminary Linac structure design is based on the following factors :

(i) For the structure between injection and 5 MeV we propose an accelerating rate increasing from 1 MeV m^{-1} at 750 keV (implying an increasing electric field) and perhaps a varying synchronous phase.)

(ii) Above 5 MeV in each of three accelerating sections there is a constant mean axial electric field, $\bar{E}$. This is the natural field configuration in a compensated structure with unexcited post couplers.

(iii) Factor (ii) implies a non-constant accelerating rate $\frac{dW}{dz}$ but one aims to keep, the variations slow and continuous (in both $\frac{dW}{dz}$ and Φ_s).

Between 5 MeV and 50 MeV the mean accelerating rate is chosen as 1.55 MeV m^{-1} which one can show leads to acceptable values for such factors as r.f. power losses and peak surface fields. Note that these "starting conditions" have been used to allow us to calculate the Linac detailed in Table 3 for the final design the electric field and synchronous phase will probably vary along the first section which will have an output energy between 5 MeV and 10 MeV. If further analysis shows that varying Φ_s along the entire Linac is clearly advantageous for high current operation then the cell lengths will be computed accordingly. However, a variable Φ_s law is inherently less flexible in operation.

5.3.3 Linac Cell Computations

A combined analytical and relaxation program [34)] is used to compute the electromagnetic fields and derived quantities in Linac cells. Possible cell designs covering the 0.5 MeV to 50 MeV energy interval have been determined by choosing several drift tube profiles and cavity diameters and computing gap sizes for $f_o \simeq 202.5 \pm 0.2$ MHz over a range of cell lengths.

5.3.4 Mean Accelerating Field ($\bar{E}$), R.F. Dissipation and Peak Surface Fields

The acceleration rate is given by

$$\frac{dW}{dz} = e\bar{E} \ T \cos \Phi_s$$

with T the transit time factor rising from ≃ 0.70 at 750 keV to a rather broad maximum of ≃ 0.83 at ≃ 5 MeV for the cell design initially chosen. However above 10 MeV the cavity parameters can be selected so that T falls slowly with W and for constant $\bar{E}$ and Φ_s, the reduction in $\frac{dW}{dz}$ between 10 MeV and 50 MeV is < 10%. This behaviour will not be significantly changed for a second accelerating section starting below 10 MeV.

Thus, for this proposal we have retained the BNL/NAL drift tube profiles (diameters 180 mm and 160 mm for W below and above 10 MeV respectively) which are used in cavities of diameter 0.94 m, 0.90 m and 0.86 m for the three sections. To obtain design values of $\bar{E}$ in each section (between 5 MeV and 50 MeV) we have numerically integrated the above equation with constant Φ_s and the continuity conditions on W and $\frac{dW}{dz}$ applied at the interfaces (10 MeV and 30 MeV). With the above results for $\bar{E}$ and assuming an approximately linear rise of $\bar{E}$ with distance between 0.75 MeV and 5 MeV one can use cell computations (which are normalized to 1 MV m^{-1}) to compute the r.f. dissipations and surface fields.

For the total r.f. power requirements one adds the dissipation on the cavity outer wall, the drift tubes, the support stems (1 per drift tube), end walls (2) and post couplers (1 per drift tube above 10 MeV) and allows an extra 30% for the effects of surface finish, joints and holes (see Table 3).

Modern surface finishes and vacuum systems have raised the maximum acceptable surface fields above the traditional value of 15 MV m^{-1}.

In the vulnerable region between drift tubes at the low energy end, the peak surface field at injection energy is less than 10 MV m^{-1} (for $\Phi_s = - 30^o$) and the maximum field elsewhere is < 14 MV m^{-1} at the beginning of the second section whatever design is finally chosen.

5.3.5 Use of the Linac Design Program~~s~~

For the purposes of the study, Linac cell lengths for several phase laws of interest were computed[31)], and the input matching and quadrupole gradients in the first section were derived for currents up to 150 mA.[20)]. These calculations will be repeated for other field and phase laws to define the optimum output energy of the first section. The next stage will be to investigate the matching throughout the entire Linac for various currents and focusing laws. A check on the non-linear effects (such as energy transfer between phase planes) causing emittance increase, will be made with the MAPRO-type multiparticle programs[35)].

5.3.6 Discontinuities and Tolerances

With the linear matching computations the aim is to produce smoothly evolving transverse and longitudinal beam envelopes in spite of inevitable discontinuities in the Linac. Transverse discontinuities can be matched out by locally adjusting the quadrupole strengths but the longitudinal focusing cannot be adjusted locally to counteract, for example, the effect of a drift space length ℓ, between sections. In fact the energy spread causes an increase in bunch length, $\Delta z/z \propto \beta^{-3} \ell^2$ which is already noticeable for the 0.20 m gap proposed at 10 MeV.

Errors in some of the parameters set-up initially such as r.f. phase. r.f. level and drift tube alignment give rise to coherent oscillations which, if sufficiently small, can often be corrected at the linac output by debunchers and steering magnets.

At $\Phi_s = -30^{\circ}$ a 1% error in $\bar{E}$ is equivalent to 1° phase error, which occurring in the third section and depending on the number of phase oscillations between 30 MeV and 50 MeV gives rise to an output energy shift of $\simeq$ 45 keV. Thus the required tolerances applying to variations within a pulse or from pulse to pulse (and applying to a complete accelerating section) will depend on the phase oscillation wave length and debuncher characteristics. Note also that a local error of 0.4 mm in longitudinal position of a drift tube at 750 keV can excite a phase oscillation of $\simeq 1^{\circ}$ amplitude.

For the quadrupoles the three important errors are displacements relative to, and rotations about the mean system axis, and quadrupole strength errors about the programmed values. Of these, the first is most difficult to get within tolerance and for an r.m.s. radial displacement error of 0.1 mm in the system composed of $\sim$ 130 drift tubes one expects a coherent radial oscillation amplitude of $\simeq$ 4 mm at 50 MeV.

It is intended to study the effects and correction of errors in more detail for the new Linac.

5.3.7 Lengths of Accelerating Sections

We have considered three options of three accelerating sections with intermediate energies (a) 16 MeV and 33 MeV, (b) 10 MeV and 30 MeV and (c) some energy below 10 MeV and 28 MeV. The choice can be based on flexibility in dynamics, post coupler requirements, configuration of r.f. power modules, intertank separation and number of cavity subsections to be manufactured. Option (b) was chosen for this study essentially on grounds of requiring only 5 identical r.f. modules but (c) now appears advantageous in giving flexible dynamics without requiring post couplers in the first section.

5.3.8 Radio-Frequency Components

a) Input Feeders: One adjustable feed loop (in 230 mm diameter coaxial line) is proposed for each r.f. output amplifier i.e. five in all (see ch. 5.5).

b) Post Couplers: These are used successfully at NAL and LASL to compensate field errors and improve the transient response in long Alvarez cavities 36). They would be straight forward to install in the second and third accelerating cavities.

c) Frequency Tuners: Copper clad steel cavities are usually made oversize and roughly tuned with a fixed perturbing bar (bulk tuner). A tuning range of ± 25 KHz is proposed for piston tuners with ± 10 KHz adjustable via a servo-system.

5.3.9 The Quadrupole Focusing System

Recent Linac designs have quadrupoles with improved iron circuits running in an FD configuration with gradients up to 100 Tm^{-1} 37). Although it was considered possible to develop higher gradient quadrupoles (120 Tm^{-1}) for operation at 520 keV, the extra safety margin and the existence of a suitable quadrupole design favours 750 keV injection energy. In Table 3 some quadrupole gradient requirements are listed for an FD system. Above 10 MeV a pulsed FD system was preferred to a direct current FFDD system as the former allows a simpler drift tube design, is more flexible in operation and can, if necessary be connected FODO. The BNL and CERN pulsers are both under consideration and it is proposed to design for the 1 ms, H^- requirement, but to install pulse forming networks for a 200 μs flat-top initially. Ways of connecting two or more quadrupoles in series for minimum perturbation of the transverse beam envelopes have been studied 24).

5.3.10 Mechanical Engineering Aspects

a) General

The three cavities (9 or 10 subsections) will be made in copper clad steel with aluminium wire seals used both for vacuum and radio-frequency joints.

It is proposed to use a large diameter bellows ($\simeq$ 1 m) to provide the flexible connection between Linac sections at 10 MeV and 30 MeV but with a much lower energy for the first section it may be easier to have a rigid connection to the second section.

b) Support and Alignment System

The design philosophy for the supports is to use a three point statically determined system for each of the two or three major sections. For supporting sets of drift tubes a removable girder system as on the 3 MeV Linac[38,39] has been studied. Up to a length of 4 m, the girder twist and deflection seem acceptable and extra costs, compared to support systems directly fixed to the cavity are not significant. Spring loaded constraints operating with a long ($\sim$ 500 mm) lever arm are preferred for position adjustment at present and a close comparison with alternative methods used in the U.S.A. should help an early design decision. For aligning the girders, spirit levels and mechanical comparators are applicable while for drift tube alignment we will study a laser scheme compared to a micro-alignment telescope scheme.

c) Drift Tube Design

With the low duty cycle for r.f. and quadrupoles, it has been possible to consider a simple cooling scheme for the drift tubes, where heat is transferred via conduction through the massive copper shell to a water cooled support stem [40].

d) Vacuum System

It is proposed to run the Linac as a single vacuum system, with standard CERN ion pumps evenly distributed to provide $\simeq 200\ \mathrm{ls}^{-1}$ per metre of structure, and at least 3 turbomolecular pumps with associated backing systems. An operating pressure $< 10^{-6}$ torr is required.

e) Water Cooling

This will be a closed circuit system with inlet water temperature controlled to $21 \pm 0.5^{\circ}\mathrm{C}$ and a flow relay on the output of each sub-circuit (e.g. several drift tubes). The total heat load is ∿ 10 kW at the maximum duty cycle envisaged ($2.4 \cdot 10^{-3}$) for the future option of H^- acceleration.

TABLE 3

Proposed Linac Parameters (see note below)

Cavity Number		1	2	3
Input Energy	(MeV)	0.75	10.03	30.02
Output Energy	(MeV)	10.03	30.02	50.10
Cavity Length	(m)	6.29	12.54	13.72
Cavity Diameter	(m)	0.94	0.90	0.86
Drift Tube Diameter	(mm)	180	160	160
Bore Hole Diameter	(mm)	20-25	30	30
Support Stem Diameter	(mm)	28	40	40
Gap/Cell Length g/L		0.22-0.31	0.20-0.29	0.26-0.32
Axial Transit Time Factor T		0.70-0.81	0.87-0.84	0.87-0.82
Synchronous Phase, Φ_s	($^{\circ}$)	-30	-30	-30
Number of Unit Cells		48	43	33
Mean Axial Field $\bar{E}$	(MVm^{-1})	1.65-2.29	2.14	2.03
Peak Surface Field	(MVm^{-1})	9.5-10.0	13.1-10.5	10.9-10.3
Cavity R.F. Power	(MW)	0.69	1.30	1.40
Beam R.F. for 100 mA	(MW)	0.93	2.00	2.00
Quadrupole Effective Length	(mm)	35-80	114	114
Quadrupole Gradient for **FD, $q = 0.75$, $I \approx 100$ mA**	(Tm^{-1})	**82-23**		

<u>Note:</u> These figures are given as an illustration of the results of the Linac design approaches proposed in this report. As indicated above, the first section will be reconsidered with the aim of reducing its output energy and choosing a phase law for optimum containment of beams up to 150 mA.

5.4 50 MeV Beam Transport

The locations of the new Linac and measuring lines, PS 50 MeV and PSB injection lines are shown in Fig. 9.

Because the Linac line cannot be the same as the present Linac-PSB injection line, two bending magnets (BH2, BH3) are required. The two deflection angles are + 17° and - 22°. Two quadrupole doublets are located between these magnets to give an achromatic deflection system. A further three doublets are placed between the Linac and BH2 for beam transport and matching into the existing PSB injection line.

Preliminary calculations using an estimated Linac emittance show that satisfactory beam transport can be achieved for beam currents up to 150 mA. In these calculations quadrupole magnets with the same aperture and maximum gradient as are at present installed between the Linac and the PSB were used. Typical beam envelopes are shown in Fig. 10.

The junction with the present line is chosen to be at IBH1. The magnet labelled above as BH3 is located here. We keep the possibilities of injection into both the PS and the PSB, of reverting to the old Linac for a limited time after commissioning the new and of running both Linacs asynchronously.

5.4.1 Bending Magnets and Power Supplies

Three bending magnets are required :

i) BH1, a switch magnet for the new measuring lines. It must be capable of deflections of ± 60 mR, and is located 6.0 m down-stream of the Linac;

ii) BH2, a 17° deflection magnet placed 28 m down-stream;

iii) BH3, a 22° deflection magnet at the present IBH1 location.

Of these magnets, two suitable ones are already available, leaving only BH1 to be acquired. Magnets BH1 and BH3 require new pulsed supplies, while BH2 will require a D.C. supply.

The magnet IBH1 can be retained in its present location as BH3, but an arrangement to rotate and realign it is needed in order to be able to revert to the old Linac.

Because of the increase in number of beam destinations, a more complicated form of routing control than now in use is needed. For these magnet supplies a stability of 2 x 10^{-4} is required.

5.4.2 Quadrupole Magnets and Supplies

A total of 12 quadrupoles is required (2 in the emittance line). These can be of the same specification and design as the air-cooled magnets on the PSB injection line. Standard stabilized supplies are described in several manufacturers' catalogues.

5.4.3 Debunching System

The term "debuncher" is really a misnomer since the purpose of the system is really to reduce energy spread and results in an inhibition of the normal debunching due to energy spread. As far as beam optics is concerned, these RF cavities are simply focusing elements in the longitudinal phase plane.

The system for the new Linac is essentially identical with that used now. The first cavity should be just before BH2 and the second and third (2nd harminic) not far after BH3. The present cavity design is valid. (One can note that RF cavities should not normally be located between BH2, BH3 where the beam is dispersed.)

The power supply and control system for the cavities is part of the overall radio frequency system.

5.4.4 Instrumentation

A number of toroidal current transformers (3) and beam position stations (5) are required. The present transformer design can be used, and it is expected that the magnetic position monitor now under development will be satisfactory.

Magnet BH2, in conjunction with position monitors can be used to measure Linac mean energy, and a feedback system which uses position error to control the RF phase of the first cavity to correct the mean energy could be developed if required.

The beam transport section between BH2 and BH3 needs to be adjusted to achieve achromaticity. For this purpose, a slit should be placed at a point of large dispersion after BH2. For a properly adjusted system, the beam position after BH3 should be independent of the radial position of this slit. A further test is available because the beam energy measurement in the present PSB 50 MeV spectrometer should not depend on the radial position of a slit sampling the beam after it has passed BH3. (Suitable slits for these tests are already in the PSB injection line.)

5.4.5 Steering Corrections

Normally there should be steering associated with each position monitor as well as one at the exit of the Linac. The currently used steering coil design, which gives both horizontal and vertical deflection is suitable.

5.5 RF System

The key feature of the new Linac RF system is the regulation of the amplitudes and phases by fast feedback loops. The required precision is given by beam dynamics considerations[41) and amounts in the present case to :

- better than 1% in amplitude;
- better than 1^{o} in phase.

The two main sources of disturbance to be compensated for are fluctuations in the amplifiers and beam loading effects, the latter depending critically upon the parameters of the tank and its adjacent transmission system. Every individual tank should therefore be imbedded in a separate closed loop; ten individual amplifier chains are thus provided to power the ten tanks of the new system. The final amplifiers will provide the tank powers as given in the table below with some 20% safety margin, allowing for plumbing losses, mismatches and additional speeding up of the large signal response :

Chain		Total peak power (kW)	Cavity power dissipation (kW)	Beam power (kW) 150 mA
1	Buncher, fundamental	10	10	---
2	Buncher, fundamental	10	10	---
3	Buncher, 2nd harmonic	20	20	---
4	Tank I	2200	700	1500
5	Tank II	4300	1300	3000
6	Tank III	4400	1400	3000
7	Debuncher, fundamental	35	35	---
8		35	35	---
9		35	35	---
10	Debuncher, 2nd harmonic	15	15	---

The common drive for all chains is generated in a crystal-controlled master oscillator, then fed to the ten inputs via a phase reference line and individual 20 dB directional couplers. Assuming some 30 dB directivity, the total isolation between the amplifier chains is ∿ 50 dB (corresponding to a maximum phase error of less than 0.2 degrees for arbitrary terminations).

A power level around 100 W CW is proposed for the phase reference line. This allows the use of a solid state output amplifier and gives on the other hand sufficient margin with respect to RF leakage from the output of the power amplifiers. The controlling elements for amplitude and phase operate at a power level ∿ 100 mW and can be built around Varactors or PIN diodes; this ensures the highest speed available with to-days components as opposed to high power ferrite phase shifters which introduce lags of the order of tens of microseconds due to ferrite "stiction" effects 42)

The low power modulators have the additional benefit that the very broad line of presently available Integrated Circuits and semiconductor components can be used in all the ancillary feedback stages.

An RF chain is composed of the building blocks detailed in the following subsections.

5.5.1 Regulating Set

The regulating set at the RF input, comprises the amplitude/phase modulators, equalizers and RF preamplifiers; it receives amplitude/phase reference signals in analogue form, allowing fast programming during the pulse in the range of 90 ... 105% in tank RF amplitude and ± 5 degrees in phase (greater excursions are only possible from one pulse to another, using slow elements like motor-driven trombones and programmable attenuators). Small-signal unity-gain-frequency of the servos is limited to ∿ 800 kHz by the delay in the cables, and a design goal of 500 kHz seems reasonable considering the additional transit time effects in the tubes and the mutual dependence of the phase and amplitude responses in the amplifiers as well as in the tank. A special problem is the heavy beam load well in excess of 50% of the total power; feed-forward information of the beam intensity will be used to preset the system approximately to the correct range leaving only relatively small corrections to be made by the closed loop.

5.5.2 Pulsed Amplifier Chain

A pulsed amplifier chain up to ∿ 30 kW power can be implemented using off-the-shelf equipment for TV transmitters, offered by many manufacturers. Since these components are designed for high duty cycles (approaching CW) and wide tuning ranges, some simplifications can be applied to the pulsed, narrow-band application in the Linac. Transistors are expected to take care of the amplification up to at least ∿ 100 W, their use at higher power being a reliability/cost problem (wear out mechanism "diffusion of metalization" for CW, "thermal fatigue" for pulsed operation).

5.5.3 Driver Stage

The driver stage (output power 300 - 800 kW, depending upon the final amplifier) can be built around several tubes of European or American make. Complete cavities for the RCA 4616 tetrode are available from two American manufacturers; these amplifiers are characterized by a very high gain which is due to the grounded cathode concept. A possible alternative is, however, the development of a new cavity in grounded grid/screen configuration with improved stability and at the same time higher output from a somewhat more powerful tetrode. Still another possibility is the use of a TH triode, loafing at much reduced ratings in a cavity similar to the output of the present Linac.

5.5.4 Final Amplifier

The final amplifier for chains 5 and 6 will consist of two cavities in parallel, equipped with TH triodes. This concept is taken over from the present machine, where each tank is fed by two cavities. Operation with a single TH triode per tank, although possible, has been ruled out : the tube would have to be run at the very limit of its ratings with poor overall reliability. On the contrary, the use of two cavities in parallel halves the individual tubes output power and permits operation at reduced cathode temperature. Life expectancy is estimated to increase by a factor of 3, so that the cost of a second tube + cavity is compensated in the long run.

The use of a single American cavity, built around the more powerful RCA triode 7835 and available ready for service from a reputed American manufacturer has also been considered. However, the equipment is relatively complicated due to the pressurized cavity and would be more expensive in capital cost by a factor of 1.6 or in operating cost by a factor of 2.1, as compared to a double PA with TH triodes of the same tube life.

The amplifier cavities will basically be the same as now in use, with the known deficiencies eliminated by a larger cavity diameter, better contact finger strips and a more reliable tube jacket using water rather than vapour cooling. Class A instead of class B operation is proposed; this will enhance the linearity as well as the power gain, keeping at the same time the plate currents fairly independent of the RF drive. These improvements require an increase in plate power and consequently more energy storage in the modulator, but will not seriously impair the total mean power balance because of the low duty cycle (1/400 for the worst case).

Rigid lines of 230 mm or preferably 305 mm diameter (with incorporated trombone sections), will carry the power of the individual amplifiers to the tanks. The coupling loops will be situated just on the air side of a flat ceramic vacuum window. This coupling configuration is used by Brookhaven and permits a particularly easy loop adjustment.

5.5.5 Modulators

Each amplifier chain will be powered by a single line-type modulator. Its pulse-forming network is composed of an LC ladder and will be charged by a highly efficient resonant system. A regulating parallel tube is provided at the output to keep the total current drain constant despite the RF drive variations, so that unwanted feedback via the plate supply to the low-power stages of the chain is minimized.

Further extension to 1 msec pulse width (for H^- operation) is prepared by providing space for additional LC sections and space for a crowbar circuit to avoid damage of the power tubes by the then increased stored energy; the pulse transformers will from the beginning be designed. for a 1 msec beam pulse.

5.5.6 Interlock System

Switch ON/OFF sequences, detection of faults and status indication will be provided by hard-wired local interlock systems in each chain. In addition, some local diagnostic equipment will allow the prediction of the remaining tube life by heater resistance and saturation current measurements. A local/remote switch allows control to be taken over by the Control Room or the computer.

The equipment enumerated above will be modular to a great extent, so that each of the ten chains is composed of basically the same building blocks.

5.6 Control System

5.6.1 Control Philosophy

Two main aspects make the operation of the new Linac markedly different from the present one :

a) Due to an improved RF system (including fast local level feedback) the setting of the RF should become as simple as the setting of a power supply.

b) Practically all electronic equipment will be accessible during a run.

A natural place for making adjustments, e.g. of the RF equipment, will therefore be locally in the quipment gallery and only essential RF parameters, level, phase etc., need to be accessible from the control room or the Linac computer. In other words, only the control parameters required for optimization of the Linac beam need to be brought to the control room. Other settings can be regarded as local and normally can be touched only by the specialist. On the other hand, since the Linac, as now, will often run unattended, it is important that sufficient information of digital form is presented to the computer and the control room in order to permit the computer and/or the operator to diagnose faulty equipment rapidly. Although the computer only accepts digital information, the operator may profit a great deal from analogue information. A multiplexed analogue system is therefore considered as an essential part of the control room equipment.

It is important that the specialist has at his disposal, locally in the equipment gallery, the power of the computer for running logs and test programs, possibly with display outputs, as well as classical tools such as scopes.

To sum up, the control room is seen as the place for optimization of the overall Linac performance, with each main equipment group (RF, preaccelerator, focusing, etc.) having its own local control rack(s), thus eliminating the need for bringing all signals to the control room. This should amount to a non-negligible saving in cable cost which can be put to balance the rather heavy cost of digitizing equipment.

Realizing that the optimization of the Linac should no longer be an artistic performance as in the past, it should be feasible to perform this operation with man-machine interfaces like the Midiconsole 43) or ISAAC 44). We should also profit from the current work on a new data bank 45). A data bank is needed for the midiconsole operation but is also useful for any program requesting control or acquisition of a Linac parameter.

We also intend to follow closely and profit from the design effort put into the control system for the SPS.

5.6.2 Control Computer

We propose to use the present Linac DEC PDP 11/45 running under RSX 11-D real time operating system. Two physical locations of the computer are possible, the present installation near the main control room or adjacent to the new Linac control room. The latter solution seems preferable, particularly if we take into account that space must be reserved at the MCR for a future Booster computer. On the other hand, we must take into account the space required in the South Hall corner for the rather extensive ancillary supplies of the pre-injector EHT generator.

The main tasks of the Linac computer will be :

- execute operator orders as given over the man-machine interface and display the machine situation;
- maintain a data bank for reference by PS, PSB computers or linac service programs, e.g. statistics programs for information on machine stability;
- communication with PS and PSB computers;
- watchdog service, detecting abnormal behaviour of a parameter. This should be recorded and signalled to Linac and MCR operators;
- general and specialized logs;
- beam quality measurements like energy spread and emittance. The request can originate from Linac, PS or PSB. In all cases, the measurement will be performed in the Linac computer and the result dispatched to the person making the request;
- automatic re-start program for getting the Linac back into operation after mains power failures;
- re-tune programs for quick changes of running conditions of the Linac, e.g. different focusing for different beam intensities;

- software and hardware tests;
- slow feedback control on a pulse to pulse basis. (The Linac pulse is too short for any computer correction within the same pulse.)

5.6.3 Satellite Computers

For the moment it is thought that the Linac Main Computer should be able to service all requests including slow feedback control on all the Linac equipment. However, when more details are known, we might be able to justify one or more minicomputers. These would then be considered as part of a given equipment and under the responsibility of the equipment designer.

5.6.4 Computer Back-Up

Since we intend to rely heavily on the computer for the Linac operation, one must consider what can be done in the case of a computer break-down.

The computer firm will have 3 - 4 service engineers on the site, but it would be preferable to be able to predict a fixed down-time in the case of a computer fault.

A complete back-up of the Linac computer would come to about 500 kFr., which seems prohibitive. If we take into account the overall PS situation, where in the future we will depend on three computers being "on the air", it looks more reasonable to solve the back-up problem for the PS complex as a whole.

5.6.5 Control Room

The new Linac control room will be situated in a corner of the South Hall close to the new Linac (Fig. 11).

We propose to adjust the Linac from a low control console equipped with the following facilities :

a) Analogue Matrix with four outputs feeding two 10 MHz true double beam scopes, each parameter having its own marked push-button for selection.

b) Computer Display with keyboard for interaction and control (e.g. ISAAC) over the computer.

c) Status Display of the TV-raster type, possibly in colour, for broadcasting of Linac status and fault warnings.

d) Midiconsole. This man-machine interface has been in use for quite some time for the Booster operation. Its response speed will be greatly improved by the use of a fast fixed head disk on the PDP 11/45 computer. A joy-stick has been tried at the present Linac with success, as an alternative to the normal push-button operation. Incremental shaft encoders, used as general knobs for parameter adjustment, will also be tried.

e) Intercom. It is proposed to use the standard PS intercom system.

f) Fast Printer for logs. A raster printer (180 ch/s) has already been interfaced on the Linac computer and seems satisfactory.

It would be preferable to install two identical consoles in the control room giving hardware back-up as well as a possibility for two people to work in parallel.

Some additional racks at the wall are foreseen for equipment like door interlock systems and radiation monitors. These do not depend on the computer but it could be useful to connect status information from the doors, as well as radiation level signals to the Linac computer. Any future demand for a remote Linac control station at the main control room can easily be implemented by using the PS inter-computer communication network plus the analogue matrix facility, resulting in a compact but powerful remote Linac control facility.

5.6.6 Digital Transmission System

For digital data transmission between the computer and the local control racks, we propose to use CAMAC.

Although CAMAC was conceived originally for the physicist, it is gaining general acceptance in the accelerator control field (NAL, LAMPF, SPS) as well as in industry. As a consequence solutions have been sought which remove the earlier restriction on CAMAC crate-computer distance (about 20 m) and on the number of crates in a system (7).

A recently proposed serial CAMAC standard system 46) will accommodate up to 62 crates and can run over several km of distance. Evidently the transmission speed will be a function of distance covered. In our case (about 200 m) we can assume a bit rate of 1 MHz.

An improvement by an order of magnitude in transmission speed is possible by the use of byte serial rather than bit serial transmission. Another possibility for interconnecting the CAMAC crates is by extension of the PDP 11 computer Unibus by special driver circuits permitting up to 200 m distance between a CAMAC crate and computer.

We propose to fix our choice after practical tests, particularly observing the noise tolerance of the different solutions.

By installing CAMAC crates along the equipment gallery, we expect to get the advantage of short cable runs compared to the situation if all signals were brought to the control room. Furthermore, the system will be more flexible for any future modifications.

5.6.7 Data Acquisition and Parameter Control

In order to save time and manpower we intend to buy, as far as possible, ready made D/A and A/D modules or systems from industry and interface the digital side to CAMAC stations. A variety of CAMAC modules already exist commercially for pulling of relays and acquisition of status information from relay closures in equipment. Control for the analogue matrix can also be interfaced to CAMAC.

Most Linac pulsing will be triggered by a master pulse followed by CAMAC delays (computer settable). For mechanical movements we propose to use mainly stepping motors and shaft encoders, of which we have already gained good experience on the old Linac.

5.7 Beam Instrumentation

The beam measuring equipment must meet two utilization criteria :

a) During the testing period (see §7.3) independently of the PS/Booster complex, measurements of the beam characteristics should be possible so that the normalization of the Linac settings can be prepared. This requires a precise and complete instrumentation (measurement of the beam density in the three phase planes) in order to compare the results with those given by the beam dynamics programs.

b) During the operational period i), to check the stability of the standard values of the beam parameters set beforehand (see §4.4), or ii), if we want to change the beam characteristics, to measure the parameters of the newly set beam.

This necessitates an on-line computer for the treatment of data and representation on a visual display unit (see §5.6).

5.7.1 Low Energy Beam Transport (L.E.B.T.)

In addition to the intensity measurements[47,48] (4 transformers), it is necessary to measure the transverse beam emittances and, if possible, the longitudinal density distribution of the bunched beam. Space restriction as well as differences in beam characteristics along the L.E.B.T. necessitated the development of two variants of the emittance measuring device[48,49,50] to be installed before and after the bunchers. (A single system of electronics is planned to serve all these emittance devices.)

To measure the longitudinal density distribution after the buncher, a coaxial probe [25] will be used during the study and the testing period. For the operational period, different types of probe and pick-up[26] can be considered depending on the improvement of oscilloscope techniques.

Prototypes of all these measuring devices will be tested and used in the 3 MeV accelerator as soon as possible during the study period.

5.7.2 Intermediate Energy

During the study programme, a complete set of measuring apparatus will be installed after tank 1 (before putting tank 2 in place) for detailed measurements of beam characteristics.

As discussed in §5.3, the distance between accelerating cavities must be kept short, leaving insufficient space for complete measurements of the beam characteristics. However, it should be possible to install a retractable system which will enable different devices to be positioned on the beam line (changing detectors will take a few seconds). e.g. beam current transformers, bunch length and transverse density measuring probes.

Some useful measurements of energy and energy spread could be possible at an intermediate energy (with reduced current) by transporting the beam through unpowered tank(s) to the measuring lines.

5.7.3 Final Energy

At the end of the Linac, two measuring lines (Figs 12, 13) will give, in one pulse, the main characteristics of one of the 3 following phase planes : horizontal or vertical (emittance line) and longitudinal (spectrometer line).

The emittance line (Fig. 12) will be similar to the single pulse emittance system which has been used operationally for two years 51), with the further possibility to make four measurements of 10 μsec duration in the same pulse (one measurement for each Booster ring).

The spectrometer line (Fig. 13) contains two analysing magnets in series enabling the density in the longitudinal phase plane to be measured. The phase to energy transformation is performed with a debuncher placed at the junction of the two spectrometers 52).

Various transformers and position detectors 53) will be put in the PS and Booster injection line. The existing measurement lines will be used to check the performance of the debuncher system and make continuous observations during operation.

6. Building and Supplies

6.1 Choice of the Site

The requirement that the new Linac be able to inject into both the Booster and the PS, leaves little choice for its location. The beam coming from the new Linac must be inflected into the present beam transport system by the Booster/PS switching magnet or upstream of it.

Two possible locations have been considered (Fig. 1). In one of them the Linac would be almost parallel to the old machine (A), in the other it would be oriented approximately perpendicular to the old machine and located in the triangular sector formed by the radial tunnels, nos. 2 and 3 of the synchrotron (B). In position A a very long free length would be available, but it involves some more complicated, hence expensive, civil engineering work near the (now unnecessary) shielding mound "Mount Citron". Position B would be somewhat more advantageous from the point of view of civil engineering, but the length available between the necessary shielding against the PS tunnel and the radial tunnel no. 2 and the access road to the North Hall, would be only sufficient if the emittance measuring set-up was suppressed. It has also the undesirable features of crossing the PS ring and rather large bending angles.

Position A was chosen for closer examination and forms the basis of this project study. It is assumed in this proposition that doors in the West wall of the South Hall are no longer essential for purposes other than the Linac and that part of them can be abandoned together with the road leading towards them. Access to the old and the new Linacs will then have to rely on traversing the South Hall in a region which has not been used for experiments in the past few years.

The most convenient position for the preaccelerator (providing space for a sufficiently large Faraday cage with a minimum of angles and corners) is then as indicated in Fig.11. The tunnel length, as determined by this choice is a few metres longer than the minimum required for a 50 MeV Linac plus emittance measurement and transfer line.

It was examined whether it would be advantageous to build the new Linac at a level a few metres above the present machine. However, cost and long-term disadvantages of the additional vertical bending were considered to counterbalance the possible savings due to reduced excavation.

6.2 Buildings

The design of the building is influenced by external constraints such as existing buildings (Linac, South Hall), Mount Citron and the level of the molasse rock. Building location and shape have been chosen to minimize the excavation and reshaping of Mount Citron (in particular to maintain as much as possible of the retaining wall opposite the South-West corner of the South Hall), and to avoid destruction or expensive modifications of existing buildings. The new buildings will be protected against the earth pressure of Mount Citron by a wall of piles anchored in the molasse. Features considered essential, such as separation of supply equipment from the accelerator tunnel and adequate space for measuring facilities have been provided.

Figs. 11,14 show layout and various cross-sections of the buildings. The constraints have led to an unusual shape for the Faraday cage, which is formed by metal sheet fixed directly on the walls of the pre-accelerator building.

The gallery for the Linac RF equipment is arranged on top of the accelerator tunnel which has its walls and roof designed for radiation shielding. In order to reduce the height required for the RF gallery, the cavities of the RF final amplifiers penetrate through the gallery floor into the service tunnel.

The control room is located in the South-West corner of the South Hall, abandoned for experiments several years ago, from where easy access to the pre-accelerator, the 750 keV beam line and the equipment gallery can be provided.

Air conditioning for the entire complex will be provided from a central plant installed in the wedge-shaped space between the accelerator tunnel and the present preaccelerator building.

If the need should arise, a second pre-accelerator column could be installed in the region above the low energy beam transport. The walls of this part of the building will be stiff enough to support the load of a supplementary Faraday cage. Space for the H.T. set would be created by digging into Mount Citron.

6.3 Radiation Shielding

Radiation shielding is required essentially against neutrons. There are also X-rays produced by the pre-accelerator and by the RF fields, but attempts at measuring the radiation level have remained inconclusive and any problem could always be dealt with by local shielding.

The requirement to leave all parts of the building except the accelerator tunnel accessible during operation, can be met by a tapered concrete wall and roof for the latter, with maximum thicknesses of 0.9 and 1.0 m respectively (see Fig.14), when the usual 54,55) assumptions about proton losses and loss distributions are made. Neutrons streaming backwards from a beam stopper can produce radiation levels in the 100 mrem/h range at the low energy end. A wall of wood or a similar material could reduce this hazard.

The Linac building will have to be declared a "radiation area" (accessible for "radiation workers" only) due to the residual levels of the order of a few mrem/h. The same is true for the control area where a radiation level of around 1 mrem/h is due to leakage from the PS shielding bridge when internal targets are operating. Reduction of proton consumption on target 1 to the order of 10^{11} ppp (South Hall used as test area only) will remove the hazard in the control area.

6.4 Supplies

Electricity

Electricity will be supplied to the new Linac from the nearby transformer substation Y1.

Loads are classified in three categories :

- Pulsed loads (mainly the RF system)
- Normal loads
- Loads needing emergency supply

The pulsed loads will be supplied from the 18 kV bus-bars through a separate transformer, the size of which has still to be determined (maximum 2 MVA). Space for an additional 18 kV breaker and for the transformer is available.

For the normal load, as well as for a possible need of emergency supply, there is enough capacity available in the existing 380/220 V distribution boards of the Y1 substation.

Water

It has not yet been decided whether demineralized cooling water can be taken from the PS ring circuit or whether a small separate refrigeration plant must be installed near the equipment gallery.

7. Budget, Staffing, Programme

7.1 Budget

The materials budget for the new Linac is summarized in Table 4. The cost figures quoted have been checked with figures available from NAL and RHEL and no deviations were found larger than must be expected in a period of rapid variation of prices and exchange rates.

TABLE 4

Project Cost Estimate

(in 1973 prices)

	Mfrs.
Preaccelerator	1.5
Low Energy Beam Transport	0.6
Linac Structure	2.7
50 MeV Beam Transport	1.7
50 MeV Measuring Lines	0.6
Radio Frequency System	3.I
Controls System	2.2
Power and Water	0.4
Air Conditioning	0.4
	13.2
Building, incl. normal technical installations, engineers fees finishing the site	4.1
Site Preparation, incl. retaining wall, earth movement services installations	0.8
Regie Labour	1.7
Model work, instruments, miscellaneous	1.5
	21.3
	=====

7.2 Staffing

The staff of this project will be made up of the existing Linac Group with the addition of a number of short-term staff (visitors and régie), some help from other groups within the division and a small number of staff posts transferred inside the division.

Under the assumption that the existing machine will be replaced in 4 years time, it is intended to stop development work on it during 1974 and thus reduce the effort to the level of pure maintenance, that is, to between 40 and 50% of the present level. This reduction is possible because specialists, though working mainly on the new project, will be available during maintenance days and for emergencies.

It appears reasonable to rely on a high percentage of visitors and régie labour for the duration of the project because the maintenance and operations staff is already available.

The effort required inside MPS-Division is summarized in Table 5. With the completion of the project the effort coming from outside the Linac Group will drop sharply. It is expected that an equilibrium level of less than 30 man-years will be attained in 1978 when the present Linac will have been closed down.

TABLE 5

	1974	1975	1976	1977
	(man-years)			
Linac Group (present strength : 37)	19	20	22	22
Transfer: - staff (from SR Group)	3	3	3	2
- programming staff (from Booster Group)	-	2	4	4
- posts	3	3	3	2
Mechanical Group: - drawing office	3	2	2	1
- vacuum	0.5	1	1	0.5
- mechanics	1	2	3	1
Power Group (cable installation)	0.5	1	1	0
Visitors	3	3	3	2

Total effort estimated : ~150 man-years

3.3 Construction Programme

It is planned, and appears feasible by comparison with other recent projects, to finish the project in less than 4 years from the date of authorization. In the programme (see Fig. 3), allowance is made for rather long periods of study at various levels of energy. As a consequence of this, the time scale for finishing the first parts of the building, the preinjector and computerized instrumentation in the 750 keV drift space is very tight and early ordering is essential. The other schedules correspond to more normal practice but it will not be easy to keep to them in view of the limited manpower available. In particular, major accidents occuring on the present Linac could draw on more man-power than anticipated and thus delay the construction programme.

Distribution : open

REFERENCES

1) C.S. Taylor (editor) : Improvement Programme : Linac - MPS/Int.LIN 69-6

2) C.S. Taylor : Linac operation and controls - MPS/LIN Note 71-14

3) C. Bovet, K. Schindl : PSB filling with a new Linac - MPS/BR Note 73-1

4) D.J. Warner, M. Weiss : Some experiments proposed in connection with Linac design problems - MPS/LINP/Note 73-1

5) M. Weiss : Choice of the preaccelerator energy for the new Linac project - MPS/LINP/Note 73-5

6) Th. Sluyters, R. Emigh : private communication.

7) J. Huguenin, R. Dubois : Measurements on a high gradient accelerating tube model, Investigation of the properties of titanium electrodes - CERN 65-23

8) J. Huguenin, G. Visconti, R. Salin, B. Desforges, R. Dubois, R. El-Bez, J. Knott : Tenue à 1,4 MV d'électrodes en alliage de titane en fonction de la distance - CERN/MPS/LIN 70-6.

9) J. Huguenin : private communication.

10) G. Visconti : private communication.

11) L.C. Reginato, B.H. Smith : A 600 kV, 10 mA d.c. Cockroft-Walton rectifier using silicon diodes at 100 kHz - UCRL-11783.

12) F. Völker (UCRL) : private communication.

13) R. Lankshear : BNL-AGSCD Spec. 669, June 26,1972 and private communication.

14) F. Chiari, R. Dubois : Préinjecteur expérimental, Hall Sud; Faisceau de protons à 500 keV de longue durée, 100 μs - MPS/LIN Note 70-6.

15) R.A. Gore, J.D. Doss (LASL) : private communication.

16) Th. Sluyters : Ion sources for proton Linacs - BNL-11293 AGS DIV 72-2.

17) F. Chiari : private communication.

18) F. Sacherer : RMS envelope equations with space-charge - CERN/SI/Int. DL/70-12.

19) B. Bru : Calcul de la focalisation quadripolaire d'un Linac et de l'adaptation du faisceau en présence de charge d'espace - Thèse à l'Université de Lyon, 1970.

20) B. Bru, M. Weiss : Computational methods and computer programs for linearized analysis of periodic structure and beam transport systems under space charge conditions - CERN/MPS/LIN 72-4.

21) M. Weiss : Bunching of intense proton beams with six-dimensional matching to the Linac acceptance - Proceedings of the 1973 Particle Accelerator Conference, San Francisco; also Int. report : CERN/MPS/LIN 73-2.

22) B. Bru, M. Weiss : Single and double drift bunchers as possible injection schemes for the CPS Linac - Proc. of the 1973 Particle Accelerator Conference, San Francisco; also CERN/MPS/LIN 73-1.

23) E. Boltezar : private communication.

24) B. Bru and M. Weiss : Tolerances for quadrupole focusing in the Linac - MPS/LINP/Note 73-7.

25) L.R. Evans and D.J. Warner : Real-time measurements of proton bunch form - Proc. of the 1972 Proton Linear Accelerator Conference, Los Alamos, p. 349; also CERN/MPS/LIN 72-6.

26) G.C. Schneider : Proposal for a resistive, non destructive UHF wideband pick-up station with beam position measurement - CERN/MPS/SR Note 73-32 and addendum.

27) P. Lapostolle and A. Septier (editors) : Linear accelerators - North Holland Publishing Co., 1970.

28) Proc. of the 1968 Proton Linear Accelerator Conference, Brookhaven.

29) Proc. of the 1970 Proton Linear Accelerator Conference, NAL, (Batavia)

30) Proc. of the 1972 Proton Linear Accelerator Conference, Los Alamos.

31) M. Promé : Effets de la charge d'espace dans les accélérateurs linéaires à protons - Thèse à l'Université d'Orsay, 1972.

32) P.M. Lapostolle : private communication.

33) P.M. Lapostolle : Lois de phase pour un Linac, Effets longitudinaux de charge d'espace - ISR/300 LIN/66-33.

34) M. Martini, D.J. Warner : Numerical calculations of linear accelerator cavities - CERN/68-11

35) M. Martini, M. Promé : Computer studies of beam dynamics in a proton linear accelerator with space charge - Particle Accelerators 1971, Vol. 2, p. 289-299.

36) C.W. Owen, J.D. Wildenradt : Experiences with post coupler stabilized structures in the NAL Linac - Proc. of the 1970 Proton Linear Accelerator Conference, NAL, Batavia, p. 315.

37) R. Damm, A. Otis, V. LoGrasso : Quadrupole focusing system for the 200 MeV Linac - Proc. of the 1970 Proton Linear Accelerator Conference, NAL, Batavia, p. 561.

38) E. Boltezar, H.F. Malthouse, D.J. Warner : A 3 MeV experimental proton Linac - Proc. of the BNL 1968 Proton Linac Conference, Brookhaven, p. 626.

39) D.J. Warner : Accelerator research and development with the CERN 3 MeV Linac - Proc. of LASL 1972 Proton Linear Accelerator Conference, Los Alamos, p. 33.

40) E. Boltezar : Temperatures of drift tubes for the new Linac accelerating structure - to be published.

41) M. Weiss : Parameters of a new Linac matched to top PSB performance, MPS/LINP/Note 72-1

42) C. Planner : private communication.

43) E. Asséo, L. Burnod, A. Daneels, E. Sigaud : System Midi-Console, CERN/MPS-SI/CO 71-3.

44) B. Carpenter : Experience with interactive control software at the CERN proton synchrotron - CERN/MPS/CO 73-1

45) A. Daneels : A data bank for on-line process control - CERN/SI/Int.DL/72-3.

46) NIM and ESONE Dataway Working Group : CAMAC Serial system organisation - NDWG 73-8, 1973.

47) A. Cheretakis : Beam transformer system for the Linac - CERN/MPS/LINP/ Note 73-8/Rev. 1.

48) N. Fewell and R. Witkover : Beam diagnostics at the BNL 200 MeV Linac - Proc. of the 1972 Proton Linear Accelerator Conference, Los Alamos, p. 54.

49) R.W. Goddwin, E.R. Gray, G.M. Lee, M.F. Shea : Beam diagnostics for the NAL 200 MeV Linac - Proc. of the 1970 Proton Linear Accelerator Conference, NAL, Batavia, p. 107.

50) R. Witkover and N. Fewell: Automatic electronic emittance device for the BNL 200 MeV Linac - Proc. of the 1970 Proton Linear Accelerator Conference, NAL, Batavia, p. 125.

51) P. Têtu : Mesure d'émittance en une impulsion du faisceau à 50 MeV - CERN/MPS/LIN 71-8.

52) P. Têtu : Single pulse longitudinal phase plane measurement - to be published.

53) C.D. Curtis, E.R. Gray, P.V. Livdahl, C.W. Owen, M.F. Shea, D.E. Young : Operating experiences with the NAL 200 MeV Linac - Proc. of the 1972 Proton Linear Accelerator Conference, Los Alamos, p. 17.

54) M. Höfert : Shielding estimations for the new Linac - CERN/DI/HP draft 1973.

55) J.Y. Freeman : Radiation safety for the new Linac project - CERN/MPS/CO draft 1973.

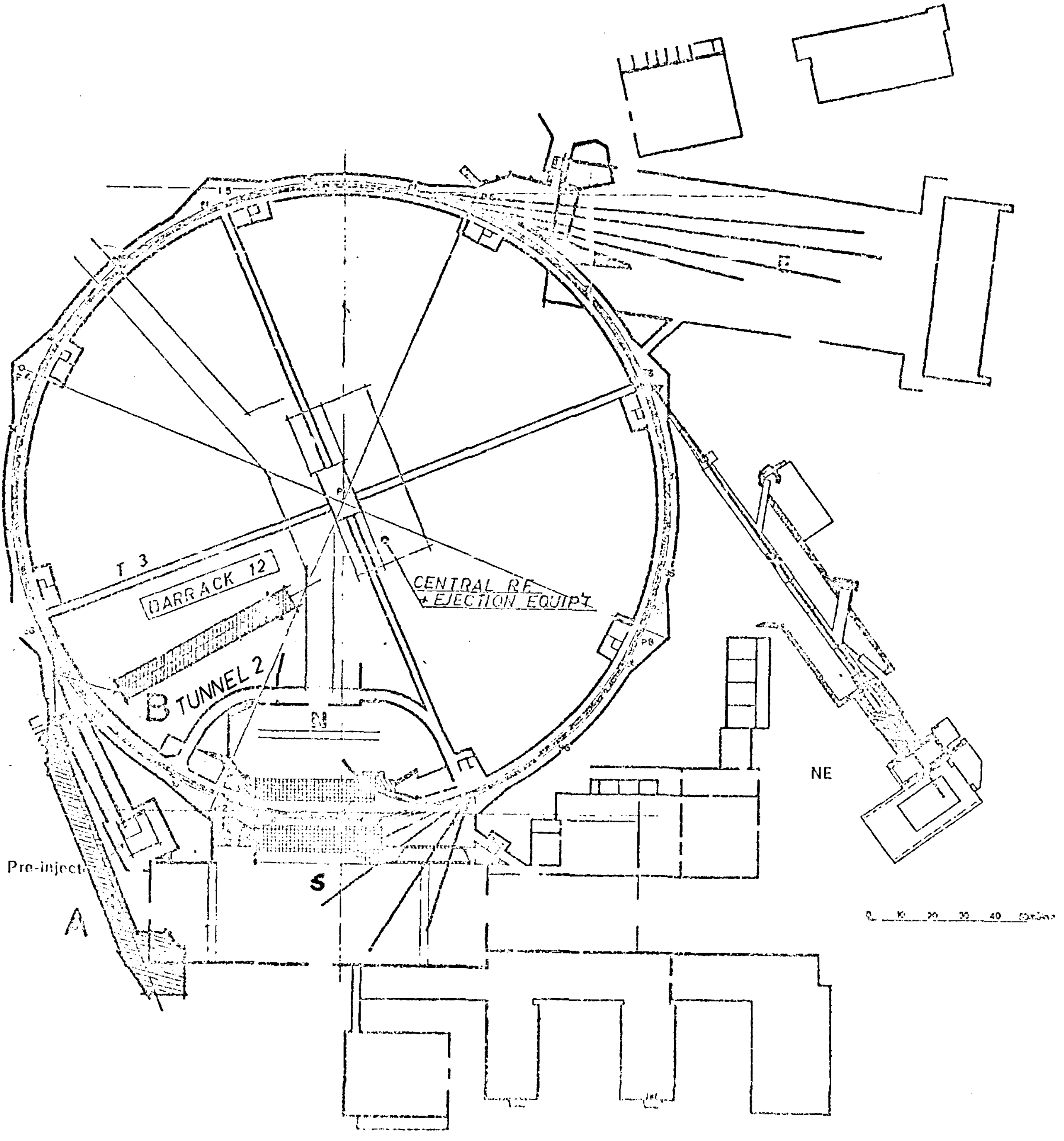
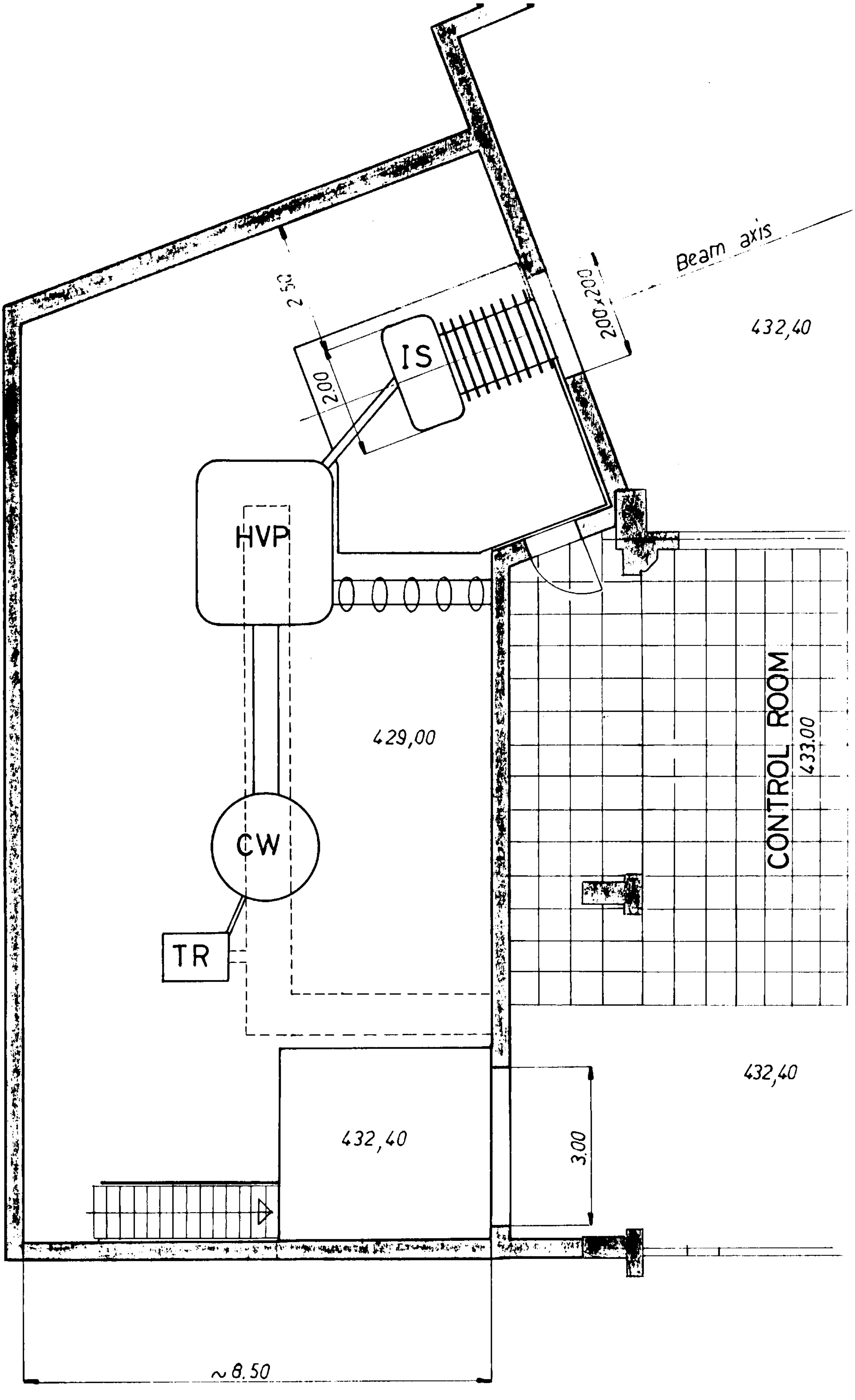
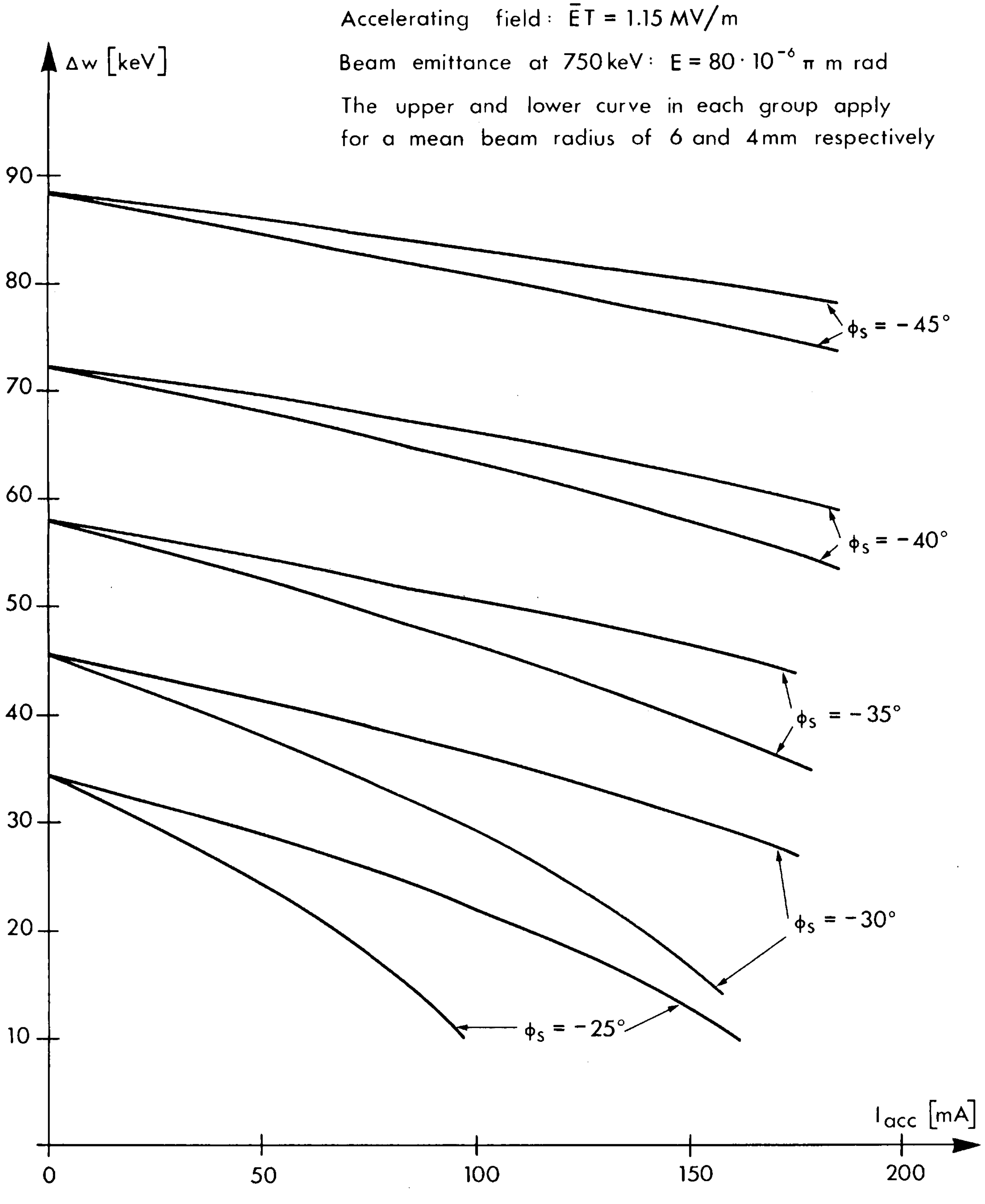

T 3
DARRACK 12
CENTRAL RF + EJECTION EQUIP'T
TUNNEL 2
B
N
NE
S
A
Pre-inject
0 10 20 30 40

FIG. 1: Two possible positions for the New Linac (A,B) relative to the PS



PREACCELERATOR LAYOUT (PROVISIONAL) FIG. 2

Scale: ~1/100



Accelerating field: $\bar{E}T = 1.15$ MV/m

Beam emittance at 750 keV: $E = 80 \cdot 10^{-6}\,\pi$ m rad

The upper and lower curve in each group apply for a mean beam radius of 6 and 4 mm respectively

FIG.3: Bucket half-height at Linac input (750 keV) as function of beam intensity and synchronous phase angle
(Approximate curves)

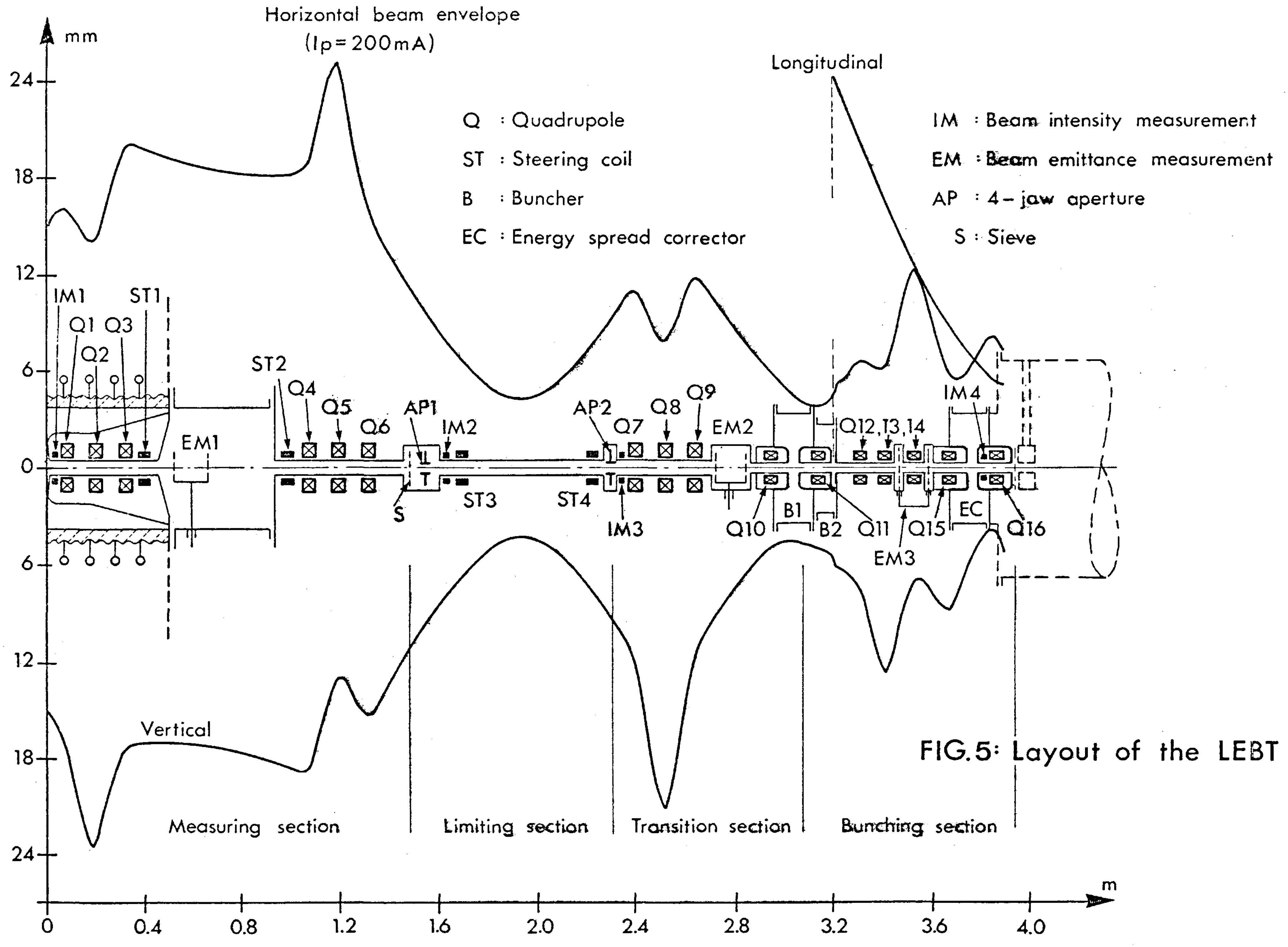


FIG.5: Layout of the LEBT

Input Conditions (preaccelerator beam characteristics)

I_p = 200 mA
E = $65 \cdot 10^{-6}$ π m rad
beam radius : ∿ 15 mm; β = 3.46
beam divergence : ∿ 20 m rad; α = - 4.36

Output Conditions (Linac matching requirements)

$\phi_s = -30^o$
$\Delta = \pm 25$ keV } longitudinal phase plane
$\alpha_H = 3.70$
$\beta_H = 0.379$ } horizontal phase plane } CLS parameters
$\alpha_V = -3.46$
$\beta_V = 0.365$ } vertical phase plane

Specification of the LEBT : length 3.90 m

Quadrupole Specific.	Quad. identif.	Length (mm)	Aperture (mm)	Gradient (T/m)
Measuring Section (1.49m)	01	60	60	- 5.89
	Q2	60	60	11.79
	Q3	60	60	- 6.96
	Q4	60	60	7.33
	Q5	60q	60	- 13.35
	Q6	60	60	7.77
Beam limiting section (0.83m)	--			
Transition Section (0.71m)	Q7	60	60	- 11.61
	Q8	60	60	19.15
	Q9	60	60	- 12
	Q10	60	30	- 2.4
Bunching Section (0.87m)	Q11	60	30	3.82
	Q12	60	30	- 13.09
	Q13	60	30	22.49
	Q14	60	30	- 22.10
	Q15	60	30	18.30
	Q16	60	30	- 26.14

Buncher voltages (kV) : B1 : 42.1; B2 : 21; EC : 24.98
Bunching efficiency : ∿ 70%

FIG. 6 : PARAMETERS OF THE L.E.B.T. (as computed)

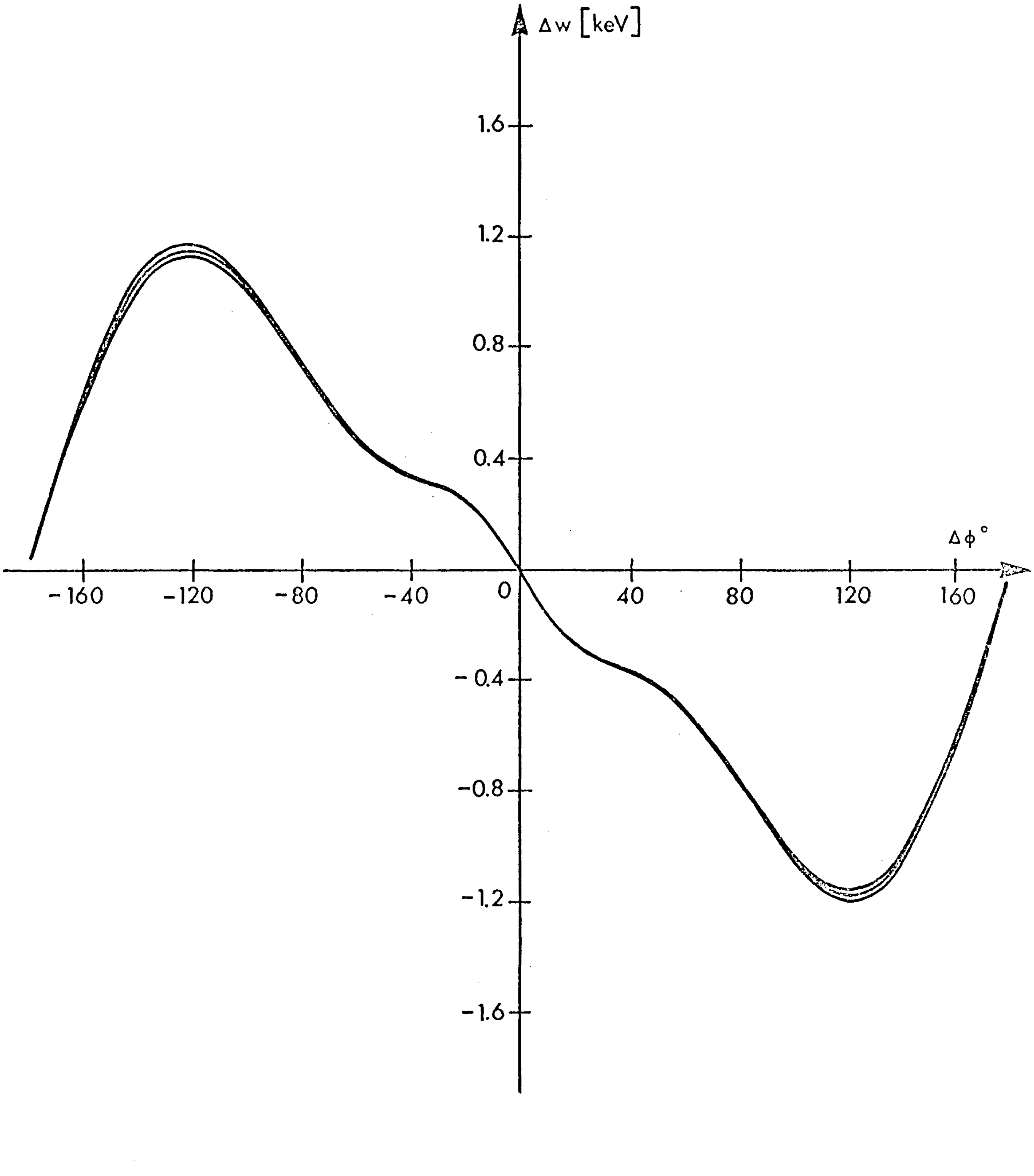


FIG. 7: Energy modulation curve of the DDHB system, normalised to $\Delta w_1 = 1\,\mathrm{keV}$ (Δw_1: energy modulation on the axis of the first buncher)

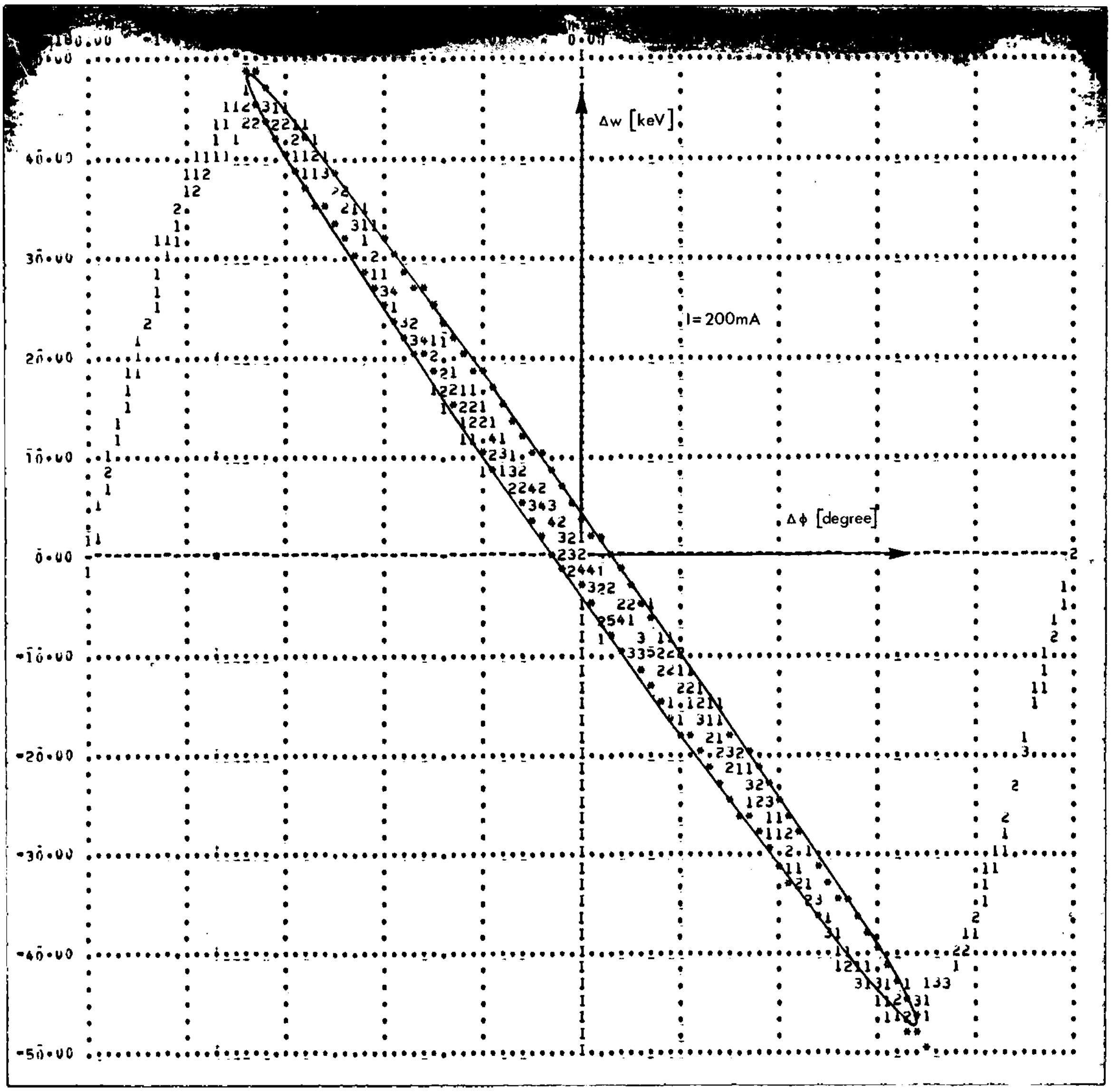


FIG. 8a : Longitudinal beam emittance after the DDHB system, calculated by a multi-particle program (in the emittance ellipse are those particles which according to L.E.B.T. optimizing programs will be trapped).

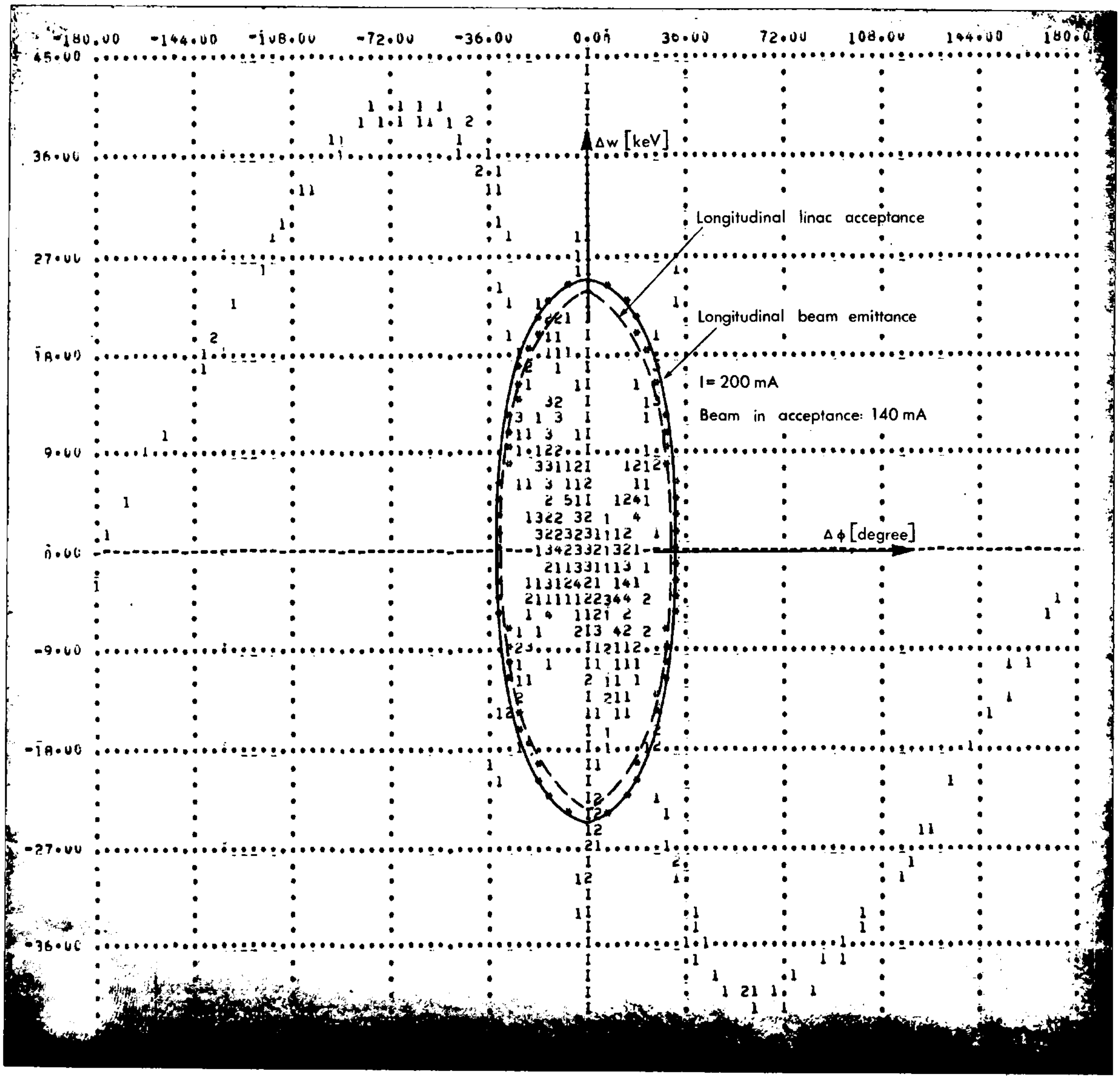


FIG. 8b: Longitudinal beam emittance at Linac input as calculated by a multi-particle program (continuous line) and the linearized longitudinal Linac acceptance (dotted line).

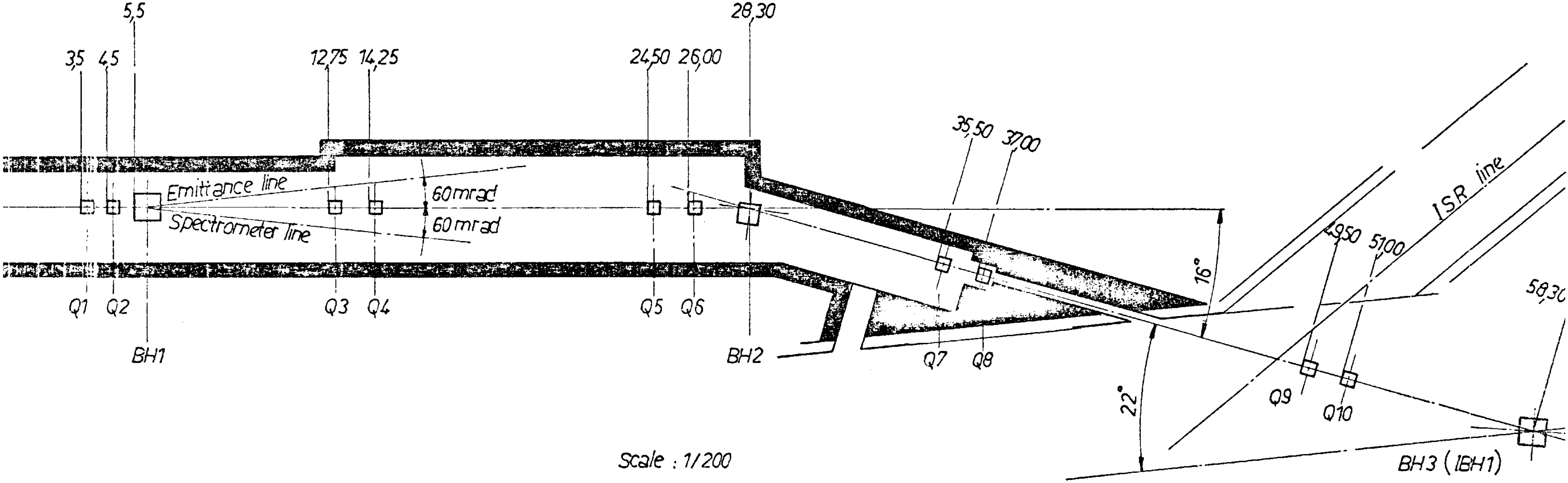


FIG. 9 : Injection line from the new linac to the PS and PSB

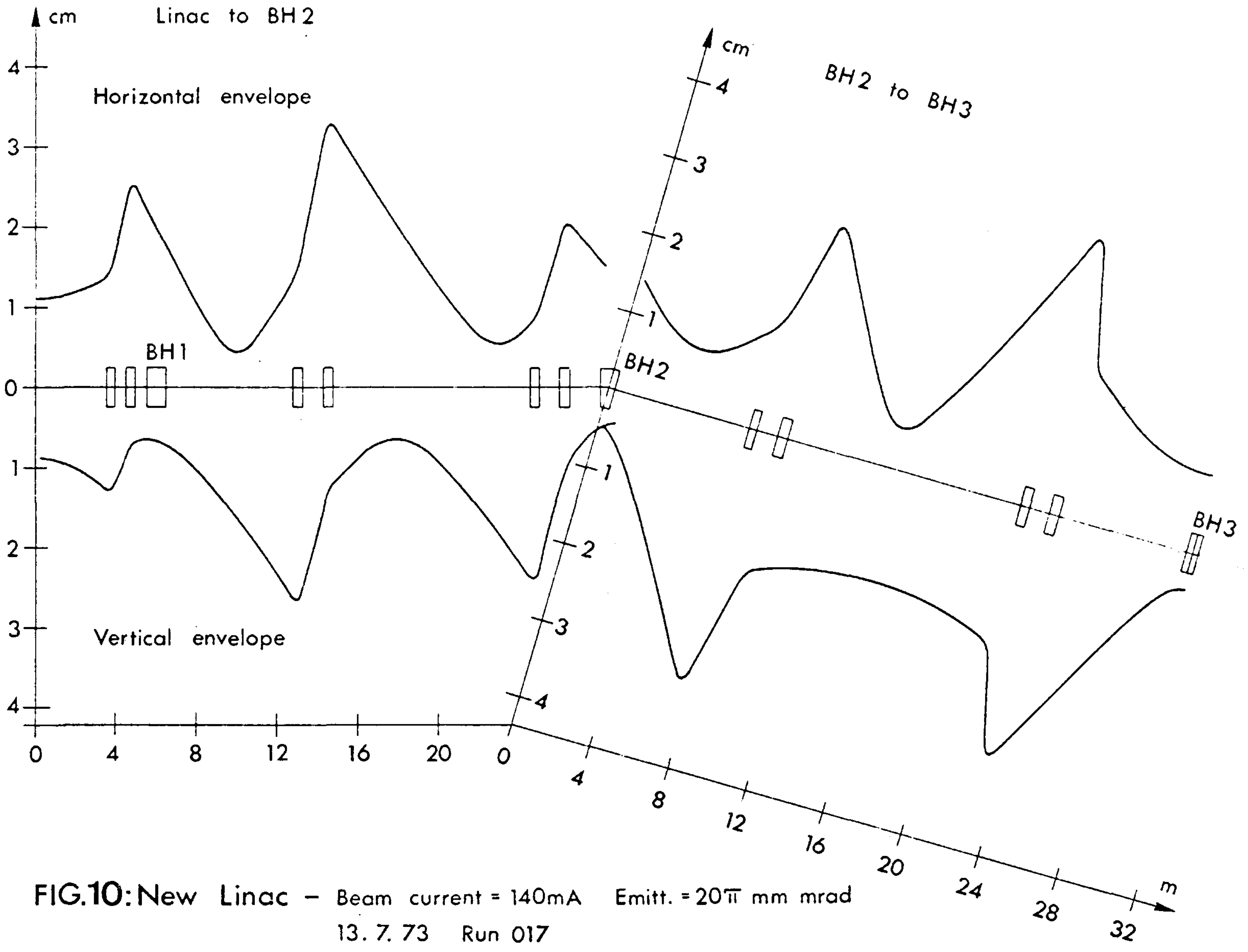


FIG.10: New Linac – Beam current = 140mA Emitt. = 20π mm mrad
13. 7. 73 Run 017

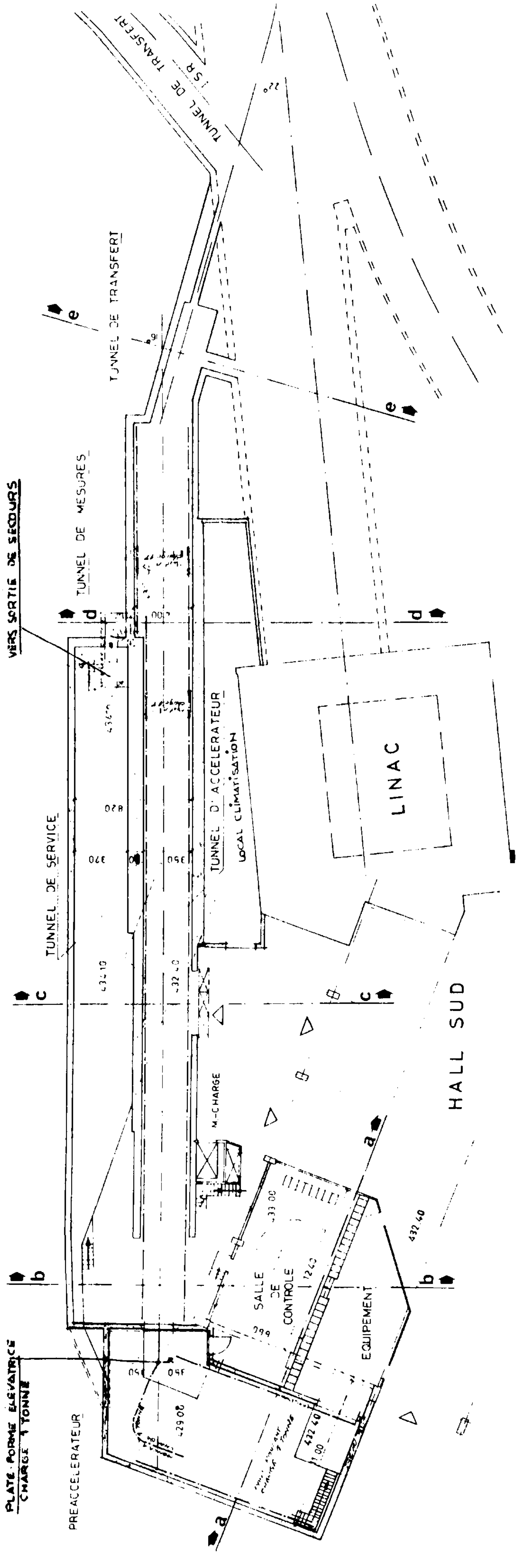
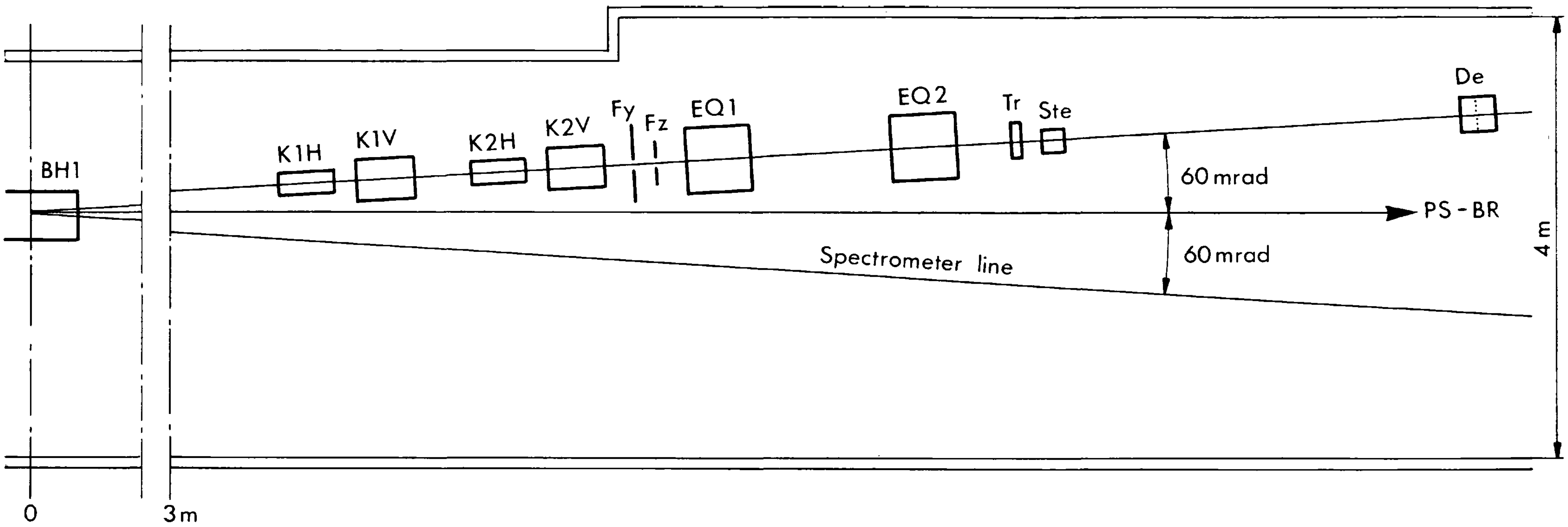

TUNNEL DE TRANSFERT
I.S.R.
22°
TUNNEL DE TRANSFERT
16°
e
e
TUNNEL DE MESURES
VERS SORTIE DE SECOURS
d
d
TUNNEL D'ACCELERATEUR
LOCAL CLIMATISATION
LINAC
TUNNEL DE SERVICE
820
370
350
432.10
432.40
c
c
HALL SUD
M-CHARGE
a
a
433.00
SALLE DE CONTROLE
1240
299
EQUIPEMENT
432.40
b
b
PLATE-FORME ELEVATRICE CHARGE 1 TONNE
PREACCELERATEUR
429.00
432.40
1.00

FIG. 11: PLAN VIEW OF THE NEW LINAC BUILDING



BH1 : Bending magnet
K1H, K2H, K1V, K2V : Kickers
EQ1 EQ2 : Quadrupoles
Fy Fz : Slits
De : Detector
Tr : Beam transformer
Ste : Steering magnet (y and z)

FIG. 12: Emittance line (Scale 1:50)

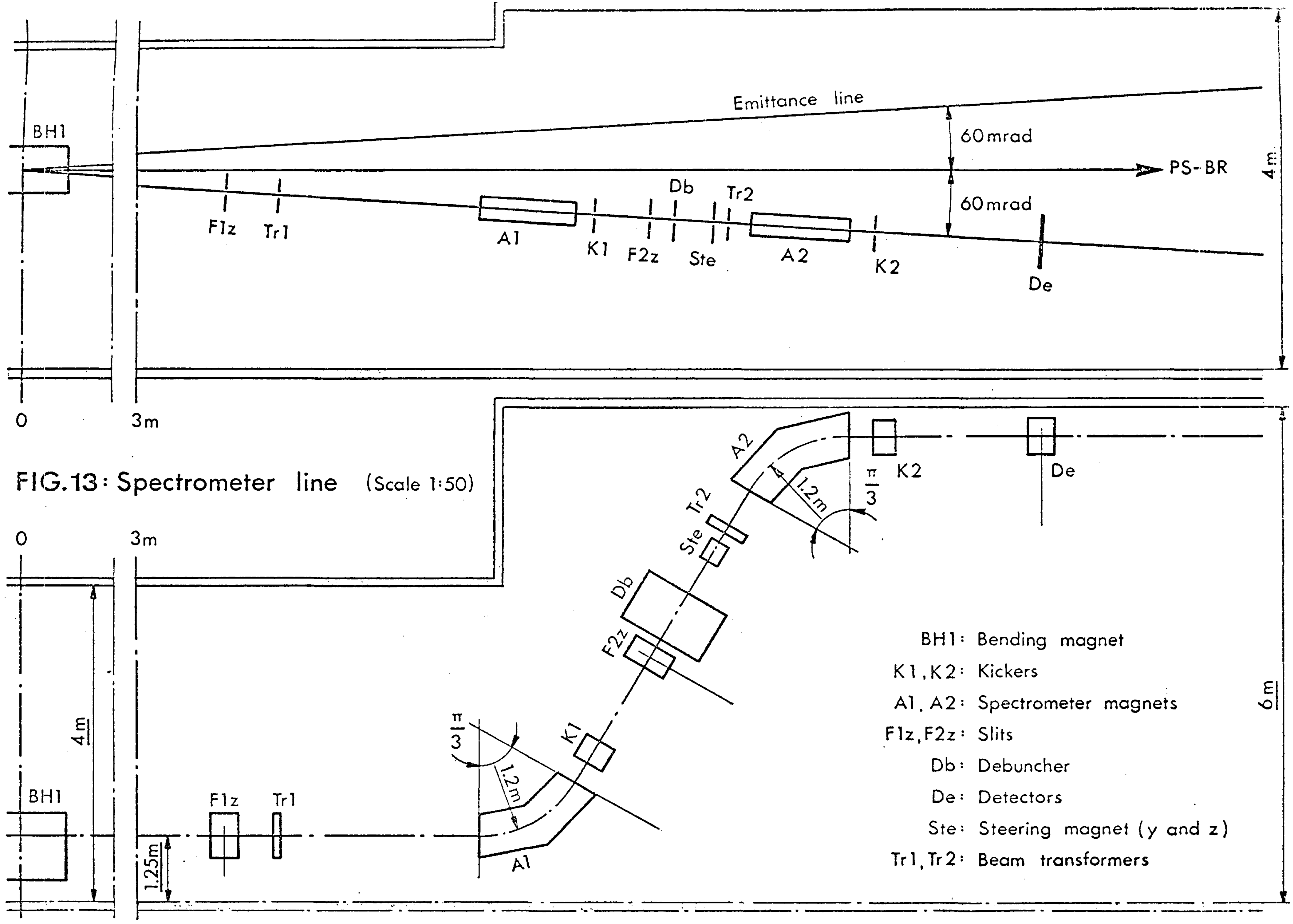
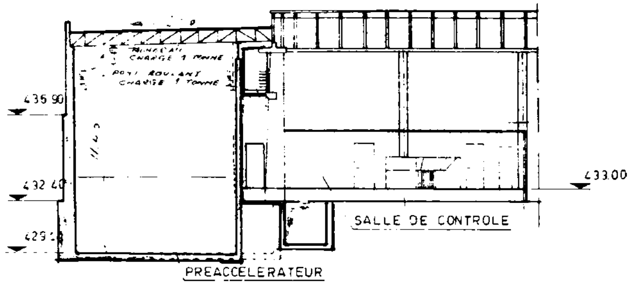
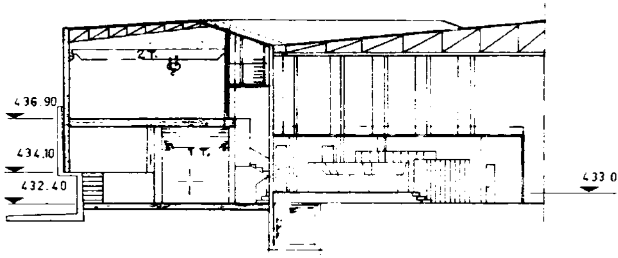


FIG. 13: Spectrometer line (Scale 1:50)



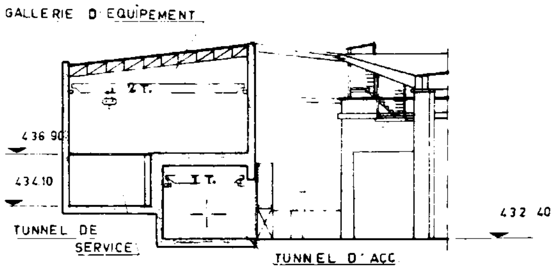
MONORAIL CHARGE 1 TONNE
PONT ROULANT CHARGE 1 TONNE
435 90
432 40
433.00
SALLE DE CONTROLE
PREACCELERATEUR

a-a



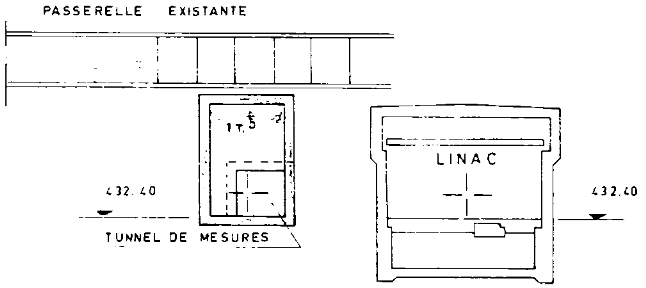
2T.
1T.
436.90
434.10
432.40
433.00

b-b



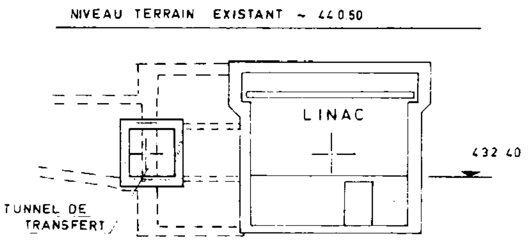
GALLERIE D'EQUIPEMENT
2T.
1T.
436 90
434.10
432 40
TUNNEL DE SERVICE
TUNNEL D'ACC

c-c



PASSERELLE EXISTANTE
1T.5
LINAC
432.40
432.40
TUNNEL DE MESURES

d-d



NIVEAU TERRAIN EXISTANT ~ 440.50
LINAC
432 40
TUNNEL DE TRANSFERT

e-e

FIG. 14: CROSS SECTIONS OF THE NEW LINAC BUILDING

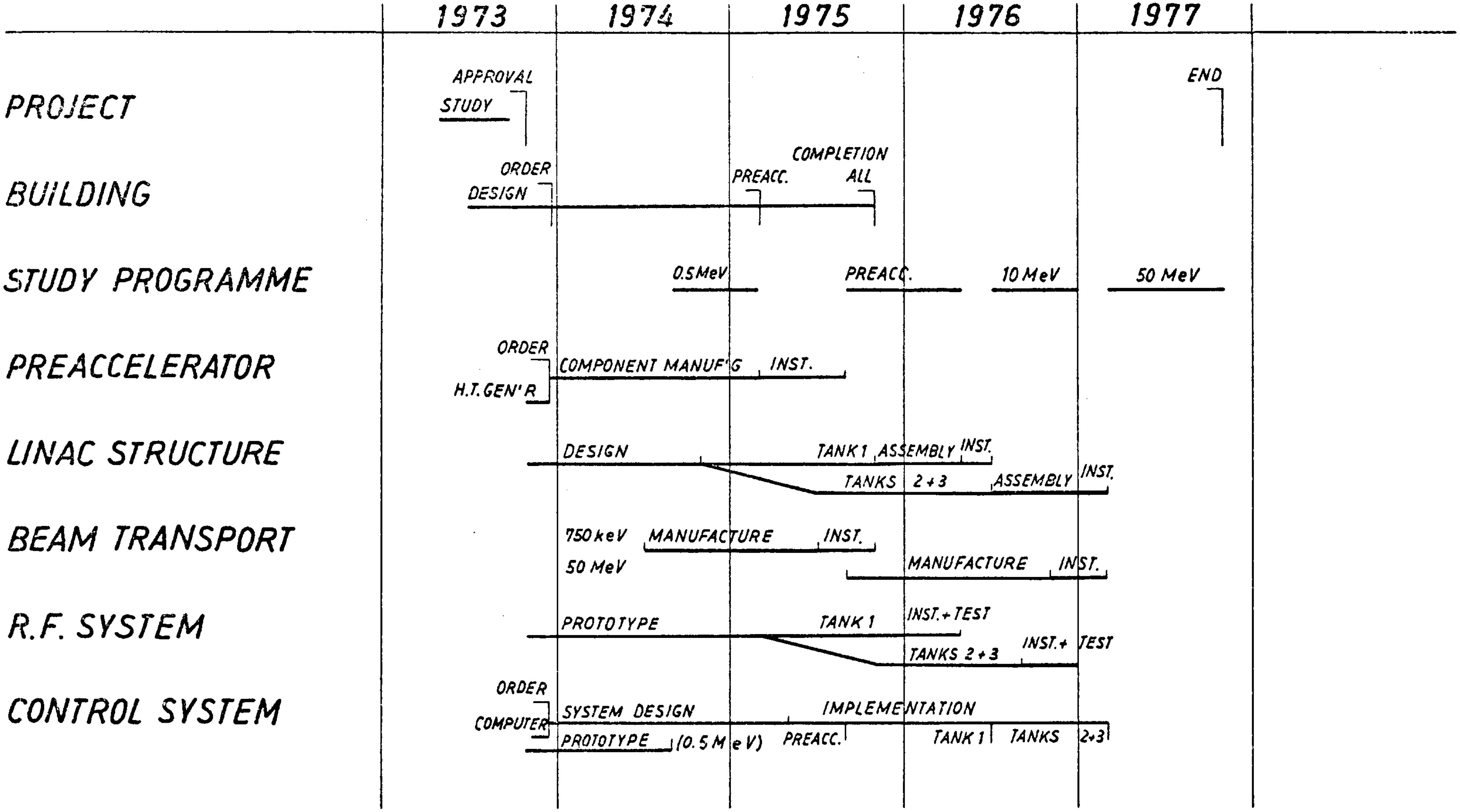


Fig. 15 TENTATIVE CONSTRUCTION PROGRAMME