Development program for high intensity proton linear accelerator

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Abstract

The conceptual design of the Engineering Test Accelerator (ETA) for actinide transmutation has been proposed by Japan Atomic Energy Research Institute, JAERI, with a beam energy of 1.5 GeV and a current of 10 mA[1,2]. This accelerator represents a large scale system when compared to the contemporary proton accelerators that are used mainly for basic nuclear physics experiments. In particular, an average proton current of 10 mA is nearly 10-50 times larger than that for existing accelerators. A beam spill should be minimized not to cause serious problems due to the high level activities induced in accelerator structures.

As a first step in the development, the low energy portion of the accelerator structure is being studied, since the beam quality is determined mainly by this low energy portion. The Basic Technology Accelerator (BTA) with a beam energy of 10 MeV and a current of 10 mA is planned to be built, which consists of ion source, radio frequency quadruple (RFQ) and drift tube linac (DTL). The high energy portion of the accelerator (high β structure) will be also studied in advance of the construction of ETA,

Survey activities and preparatory design works have started in 1989. Studies for the optimization of the accelerator system and the conceptual design of accelerator structure are being carried out in 1990 which will be followed by various R&D activities in 1991. Investigation for an accelerator building and utilities has been continued simultaneously.

1. The present status of intense accelerator

For last two decade, various advances in accelerator technology have been made. Among them, the following four items are significant.

(1) Newly developed accelerator structure, radio frequency quadruple (RFQ) has given great impetus to the improvements of the beam quality and beam intensity. This was fist proposed by Kapchinskii and Teplyakov[3]. This structure was, then, intensively studied and put in practical use in Los Alamos[4]. The RFQ has been operating successfully in various accelerator laboratories all over the world,

(2) Detailed study on beam dynamics property has been carried out and the effect to the beam characteristics now becomes well understood.

(3) Because high intensity accelerators use high power micro wave RF (radio frequency) source as a power supplY, developments of efficient and high power RF sources (tetrode or klystron) are extremely important. Various RF sources now become available for various accelerator frequency range between 100 MHz to several GHz.

(4) Due to the very rapid development made on electronics equipment and computer technology, elaborate control and beam diagnostics are now possible so that operation of a large and complicated accelerator system can be done reliably, safely and also economically.

In the past, several high intensity accelerators were proposed to build and partly operated. A large amount of R&D results have been accumulated. In 1950's, the deuteron accelerator was proposed and built in Livermore called MTA, Material Test Accelerator for nuclear fuel ^{239}Pu production with the goal of 500 MeV and 300 mA. The acceleration of the beam of 30 MeV and 50 mA was actually achieved. Situation on uranium fuel supply, however, was changed later on and this project was canceled. After long ceased, this accelerator breeding design study has been again continued in 1970's at BNL, ORNL and ANL, and they have accomplished to prove its technical feasibility.

In LANL, neutron distribution and spallation nucleus yield have been studied as the research activity for FERFICON (FERtile to FIssile CONversion) project in the past. Recently, they are proposing the high intensity CW proton accelerator ATW (1.6 GeV, 250 mA) for accelerator-based transmutation of nuclear waste. LANL has also proposed the FMIT project (Fusion Material Irradiation Test Facility) jointly with Hanford Laboratory. In that project, high intensity RFQ was built and successfully operated with hydrogen molecular beam of 50 mA. At the present, the study of more intensive version IFMIF (35 MeV, 1 A) is being continued.

In Chalk River, Canada, the high intensity proton accelerator project was proposed for the nuclear fuel cycle and still various R&D works are continued with the emphasis on the continuous was (CW) operation.

For pulsed neutron source for material researches, a 1.1 GeV, average 5 mA accelerator SNQ (Spallations-Neutronenquelle) was proposed in Julich, Germany. The conceptual design study and some detailed R&D works were completed.

In Table 1, the present status of the high intensity accelerator including existing and proposed accelerators is given. At present, the most high intensity accelerator is LAMPF in LANL which accelerates a 800 MeV and 1 mA proton beam. This accelerator was built in 1972 and has been stably operated for 20 years. In Europe, ISIS at the Rutherford and Appleton Laboratory, England, and SINQ at Paul Scherrer Institute, Switzerland, are routinely operated for the neutron source, and meson and muon production. The detailed references for above mentioned accelerators can be found elsewhere[5].

2. The time schedule of the ETA and BTA development

The research plan for developing the high intensity proton linac is proposed by JAERI with the goal of the project as shown schematically in Fig. 1.

(1) The 1st step development. (BTA)

The basic technologies are investigated for the development of a proton accelerator within the range of 5 - 6 years. The research building will be built at the Tokai Establishment of JAERI. The feasibility study and trade-off study for the accelerator and transmutation plant are carried out in this initial period. The various activities in the accelerator research field will be organized to provide technologies and staff that are required to build such an intensive accelerator. The Basic Technology Accelerator BTA with a current of 10 mA and an energy of 10 MeV will be constructed and operated for these initial studies. The conceptual layout of BTA is shown in Fig. 2.

(2) The 2nd step development. (ETA)

A proton accelerator ETA for the research purposes with a 10 mA current and 1.5 GeV energy will be designed and constructed. The construction is expected to start in about 1996, after several check and reviews have been completed. The various engineering tests of the incineration process, including medium and large scale integral test, mock-up test and prototype experiments, will be made using this accelerator. Some other accelerator applications such as material researches, radio-isotope production, nuclear data measurement, meson physics and radiation therapy will also be carried out. The schematic layout of ETA is given in Fig. 3.

(3) The 3rd step development. (commercial Plant)

A commercial incineration plant utilizing an intensive proton linac will be constructed, after all the engineering and pilot plant tests both for accelerator and target system have been completed. As an industrial plant, every accelerator parameters such as proton energy, current and operational mode as well as the target system will be fully evaluated and optimized.

3. Conceptual design study for high intensity accelerator

(1) General consideration

The main characteristics of the BTA and ETA is the high beam current. In the conceptual and detailed design of the system, much attention has to be paid in order to maintain the small beam spills. The caution has to be also taken to the design of other various parts such as the radiation shielding and beam controlling on the same reason.

As the first step of the development for BTA, the accelerator structure consists of the following components; ion source, radio frequency quadruple (RFQ) and drift tube linac (DTL). The high energy portion of the accelerator (high β structure) will be studied also in advance of the ETA development.

The parameters for the BTA are determined by aiming at proving the validity of the low energy part of the ETA. Various tests of the characteristics of the accelerator structures will be conducted so that the design and operational experience can be accumulated. The beam energy is chosen to be 10 MeV, below the Coulomb barrier to avoid proton induced reactions in accelerator structural materials.

The acceleration frequency of 200 MHz is chosen for our purpose both for RFQ and DTL mainly due to the availability of RF source and heat removal problem. The high frequency has a problem of the heat dissipation per unit area, therefore it is easy to occur resonance frequency drift, gas release and electric discharge.

As the first step of the accelerator operation, low duty operation is appropriate to adjust the various parameters so that the adequate parameters can be obtained before future full CW operation. Therefore, the pulse operation is prepared for the optimum development step with the necessities to provide sufficient electric power supply for CW and pulse operation.

(2) Ion source

Duoplasmatrons and the duoPIGatron[6] have been widely used in proton linacs as an intense ion source. Multi-cusp type ion source has been developed for neutral beam injectors (NBI) in fusion reactor heating devices[7]. Further development of intense ion sources is necessary for high intensity and high duty operation. In the case of accelerator applications, necessary beam qualities such as emittance and beam size for acceptance into the following accelerator structures is more severe than those that contemporary sources can provide. Simultaneous acceleration of the H^+ and H^- beam may be also desirable for the later basic research proposes. The injection voltage of about 100 keV is chosen at present. Table 2 shows the preliminary parameters for the BTA ion source.

(3) RFQ

The RFQ is the only choice for an accelerator structure that can accelerate an 10 mA proton beam up to 2 MeV with good beam quality acceptable by the next structure DTL. The various evaluation and test of the RFQ are still needed with low and high power RF tests, and actual beam test during the construction of the structure. The design parameters of the RFQ is shown in Table 3.

As the test calculations for the design of the RFQ for our purpose, the computer code PA RMTEQ was used. An example of calculated result of the beam dynamic calculations is shown in Fig. 4.

(4) DTL

As DTL development, a high electric field and a high frequency are preferred, because of the higher effective shunt impedance and the efficient longitudinal focusing that result in a shorter total accelerator length. Our accelerator requirements, however, call for extremely small beam spill in the high energy section resulting in the 200 MHz structure with the inner diameter size of 88.63 cm and the tank length of 380 cm.

The test calculations for the design of the DTL have been made using the computer code PARMILA. The tentative parameters for the test calculation is given in Table 4 and an example of the beam dynamics calculation is shown in Fig. 5.

(5) RF source

As the first step of the development, the RF power source of 1 MW (peak) is necessary for 10 MeV beam energy and 10 mA beam current. While the klystron for the high frequency region above 350 MHz have become currently available for the MW class RF source, those for the low frequency region are difficult to obtain. The klystrodes newly developed are only available so far with the several hundred kW output power range. The triode or tetrode tubes are, therefore, considered to be our choice used for BTA with multistage amplifier configuration. Table 5 shows the presently available 200 MHz hard tube amplifiers. If the development of the MW class klystron or Klystrode with the 200 - 350 MHz range and CW operation are available on the commercial base, these amplifiers will be useful for our purpose.

(6) High β linac

The detailed development works of the high β linac will be started after the first step accelerator development has been completed, because their R&D for this section is still in progress. There could be several possible candidates for the structures, either single cavity or coupled cavity structures. In particular, as to the coupled cavity structures, many candidates are now being investigated in various laboratories: side coupled structure (SCS), alternating periodic structure (APS), disk and washer structure (DAW) and annular coupled structure (ACS). After 5 years development period, some new conceptual design may also come out other than those choices. We have to investigate and carry out survey work for these choices. The choice itself will depend on many aspects such as the space of the accelerator building, the capacity of power supplies and the availability of RF sources.

4. The summary and works carried out in 1989 and 1990

Fig. 6 shows the time schedule for the R&D program and construction for BTA and ETA. In 1990, we are in the stage of system and conceptual study. Actual R&D works will be started in 1991 with the design and construction of various prototype accelerator structures for cold model test and hot model test. For hot model test, RF power source will be prepared and measurements of the electric magnetic characteristics of the accelerate structure will be conducted. Problems of heat dissipation and heat removal in the structure will be studied. The validity of the various computer design programs which we are now using, has to be checked by comparing the results from R&D works with the calculated results.

We are expecting to start accelerator construction of BTA in 1992 and complete the fabrication and assembly till the middle of 1994. The test operation will be started in 1994. The detailed design works for the ETA construction is planned to begin in 1996. Simultaneously, the conceptual design study and various trade-off study for the accelerator parameters of ETA is being carried out before the actual construction will start.

The major activities for the developments in 1990 are summarized as follows,

1) Survey activities of high intensity proton accelerators. Preparation and test run of computer programs for design calculation.
2) Determination of operation mode (CW, duty cycle, RF frequency, energy configuration etc.)
3) System studies of Basic Technology Accelerator.
4) Conceptual design studies of accelerator elements: Ion source, RFQ, DTL, RF power source, control system etc.
5) Design of cold and hot models for RFQ, DTL and RF source.
6) Studies of utilities such as electricity, water consumption, space and layout required for the BTA building.
7) Trade-off studies of the Engineering Test Accelerator.

5. Acknowledgement

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A COMPARISON OF EXISTING AND PROPOSED HIGH INTENSITY PROTON ACCELERATORS

1990/1/20

Name	Country	Lab.	Type	Energy (MeV)	Current (mA)	Width μs	Rep. Rate (Hz)	Power (NW)	Status
KENS	Japan	KEK	synclo	500	0.006'7	10,100	20	0.003	Operating
IPNS I	us	ANL	synclo	500	0.012	3,10	5	0.006	Operating
TNF	Canada	TRIUMP	cyclo	450	0.100	CW		0.045	Operating
1s1s	UK	RAL	synclo	800	0.200	3,10	50	0.16	Operating
SINQ	Swiss	PSI	cyclo	600	1.	CW		0.6	Operating
LAMPF	us	LANL	1 inac	800	1.	500	12	0.8	Opearting
JHP	Japan	KEK	linac	1000	0.200	400	50	0.20	Proposed
SNQ	FRG	KFA	linac	1100	5.	250	100	5.5	Cancelled
ASPUN	us	ANL	synclo	1100	3.5	3,10	35	3.85	Proposed
EURAC	EC	Ispra	linac/cyclo	600	6.	CW		3.6	Proposed
JAERI	Japan	JAERI	linac	1500	10.	CW/pulse		15.	Proposed
DEMO	Canada	CRNL	linac	1000	300.	CW		300.	Proposed
ATP	us	LANL	linac	1600	250.	CW		400.	Proposed

Table 1 A comparison of existing and proposed high intensity proton accelerator

High Brightness H^+ Ion Source

Overall		
	Energy	50-100 KeV
	Current	100mA(H^+)
	Duty Factor	CW
	Emittance	0.5πmm·mrad
	Proton Yield	>9070
	Impurity	<1 70
Plasma Generator		
	Type	Multicusp
	Size	20cmϕ×17cm
	Plasma Production	ECR(2.45GHz)
		Arc(LaB6 Cathode)
		Arc(W filament)
	Operating Pressure	0.2 Pa(H^+)
Extractor		
	Type	Two-stage Extraction (4 Grids)
	Insulator	Alumina Ceramic
	Current Density	200mA/cm^2(H^+)
	Aperture	8mm(H^+)

Table 2 Preliminary design parameters for ion source

RFQ Parameters

Energy (Shaper Output)			0.068 MeV
(GB Output)			0.51 MeV
Vane Length RM			1.54 cm
	Shaper		56.87 cm
	GB		64.34 cm
	Accelerator		102.74 cm
	Total		225.49 cm
Cavity Diameter			66 cm
Minimum Aperture			0.384 cm
Maximum Modulation Factor			2.24
Vane Voltage			0.128 MV (1.8Ek)
Synchronous Phase			-30 deg.
Wall Loss Power			221 Kw
Beam Power			216 Kw
Transmission			96.0 %
Normalized Emittance			
	x	Input (loo%)	0.049 π·cm·mrad
		output (loo%)	0.38 π·cm·mrad
		output (90%)	0.095 π·cm·mrad
		Output (rms)	0.020 π·cm·mrad
	Y	Input (loo%)	0.046 π·cm·mrad
		output (loo%)	0.38 π·cm·mrad
		output (90%)	0.11 π·cm·mrad
		Output (rms)	0.023 π·cm·mrad
	z	Input (100%)	2.98 π·MeV·rad
		output (loo%)	0.38 π·MeV·rad
		output (90%)	0.015 π·MeV·rad
		Output (rms)	0.0026 π·MeV·rad

Table 3 preliminary design parameters for RFQ

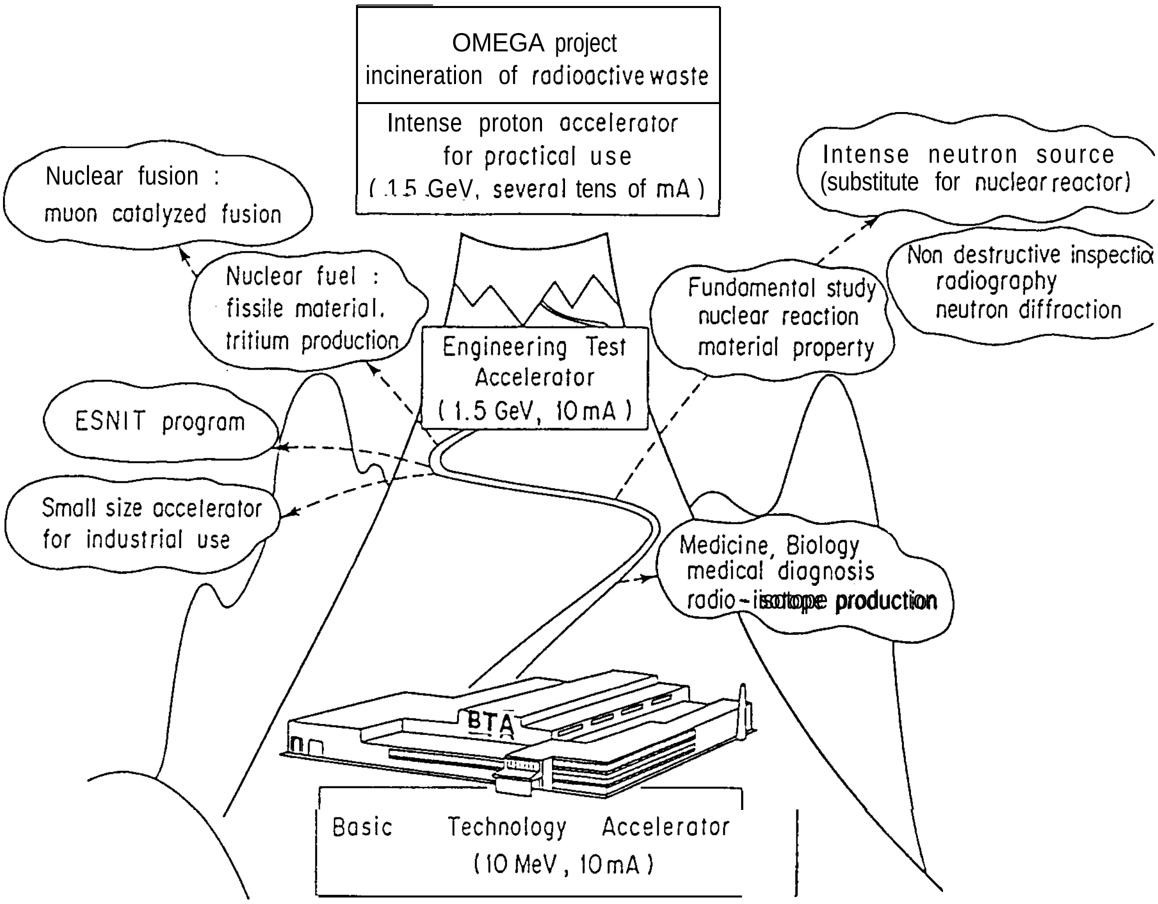
DTL Parameters

Length of Tank		380.97 cm
Inner Diameter of Tank		88.63 cm
Drift Tube :		
	Outer Diameter	18.00 cm
	Inner Diameter	2.00 cm
	Cell Length	
	(at 2MeV)	9.91 cm
	(at 6 MeV)	16.85 cm
	(at 10 MeV)	21.57 cm
	Gap Length	
	(at 2 MeV)	1.94 cm
	(at 6 MeV)	3.97 cm
	(at 10 MeV)	5.60 cm
	Number of Cell	23
Synchronous Phase		-30 deg.
Wall Loss Power		900 Kw
Beam Power		800 Kw
Transmission		98.6 %
Normalized Emittance		
x	Input (100%)	0.38 π·cm·mrad
	output (loo%)	1.1 π·cm·mrad
	output (90%)	0.51 π·cm·mrad
	Output (rms)	0.097 π·cm·mrad
Y	Input (100%)	0.41 π·cm·mrad
	output (loo%)	1.7 π·cm·mrad
	output (90%)	0.52 π·cm·mrad
	Output (rms)	0.077 π·cm·mrad
z	Input (loo%)	0.061 π·MeV·rad
	output (loo%)	0.14 π·MeV·rad
	output (90%)	0.037 π·MeV·rad
	Output (rms)	0.0062 π·MeV·rad

Table 4 Preliminary design parameters for DTL

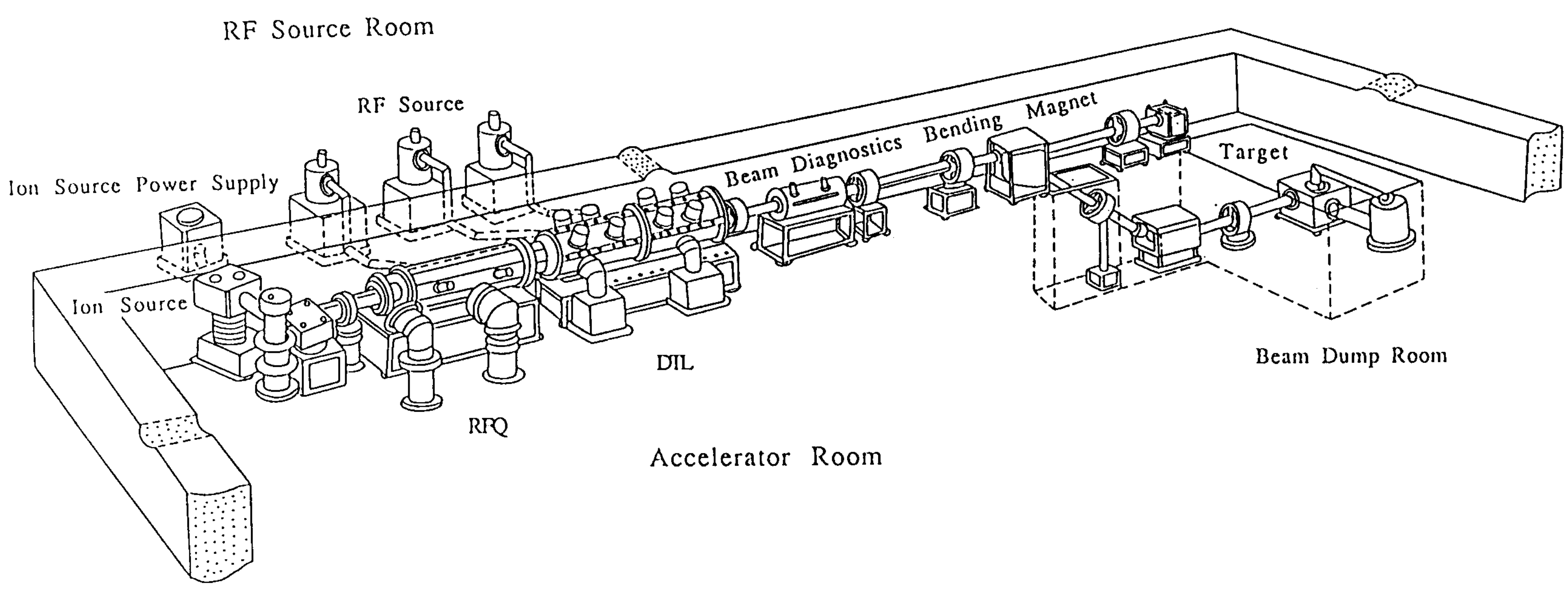
	RS2074SK	RS2042S K	8973	7835	TH526	TH116
Manufacturer	Siemens	Siemens	Eimac	Burle	Thomson	Thomson
Type	Tetrode	Tetrode	Tetrode	Triode	Tetrode	Triode
Frequency (MHz)	50-200	17-200	20-200	200-300	200-220	1-250
Output Power (MW peak)	1.6 (108 MHz) (5ms)	1 (150 MHz) (4ms)	1.6 (70MHz) (1ms)	4 (250MHz) (2ms)	2.5 (155MHz) (300 μ s)	2.2 (200 MHz) (700 μ s)
Duty Factor (%)	25	40	33	6	3	3
Anode Voltage (I(v)	24	14	20	30	24	30
Efficiency (%)	65	66		60.6	64.7	48.1
Applicatipon	GSI NIRS	GSI RCNP	JT60 JET	BNL FNAL LANL		KEK CERN

Table 5 the presently available 200 MHz hard tube amplifiers.



Goal of the Basic Technology Accelerator Development

Fig. 1 Goal of the Basic Technology Accelerator



Basic Technology Accel=ra or (BTA

Fig 2 Conceptual layout of the Basic Technology Accelerator

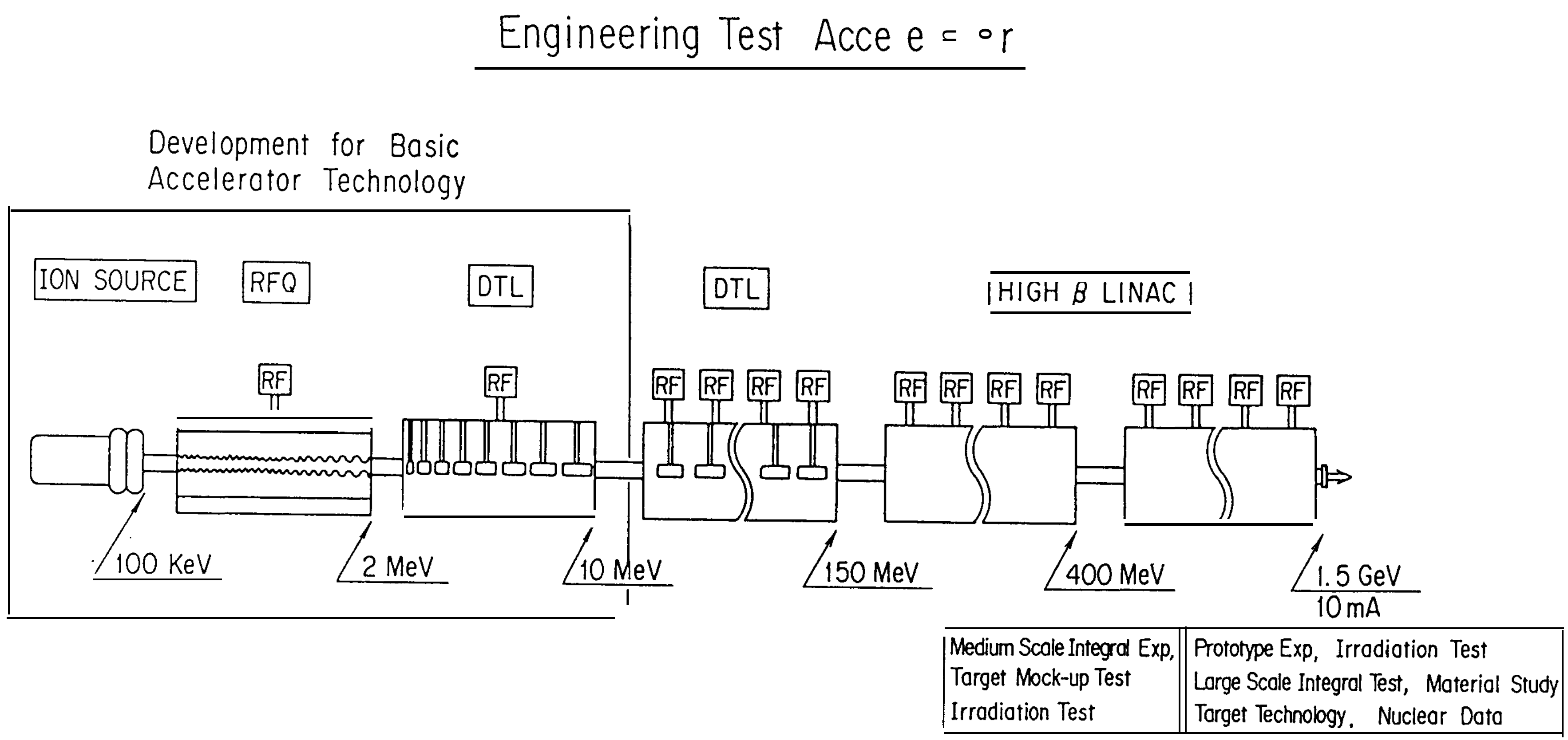
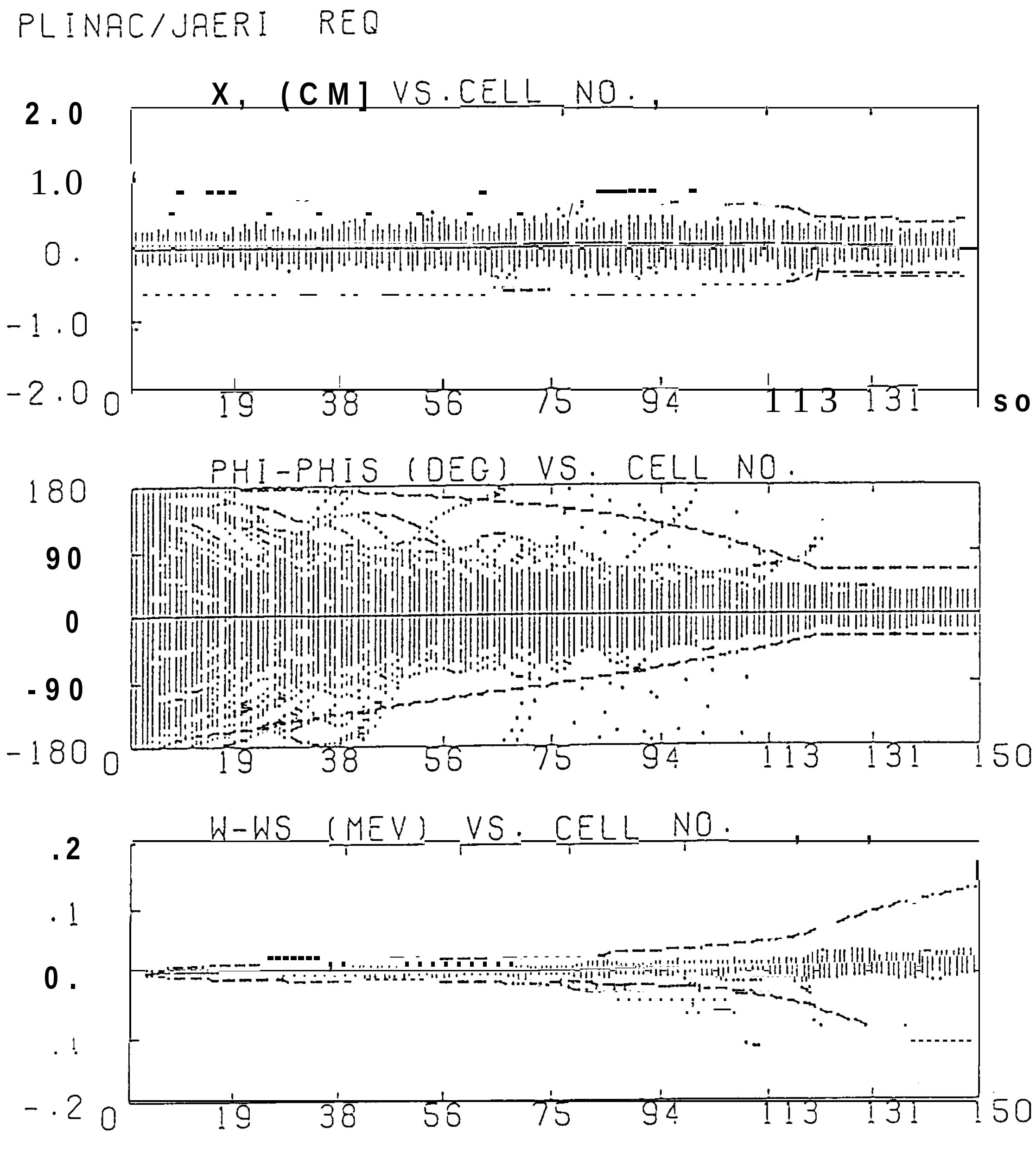
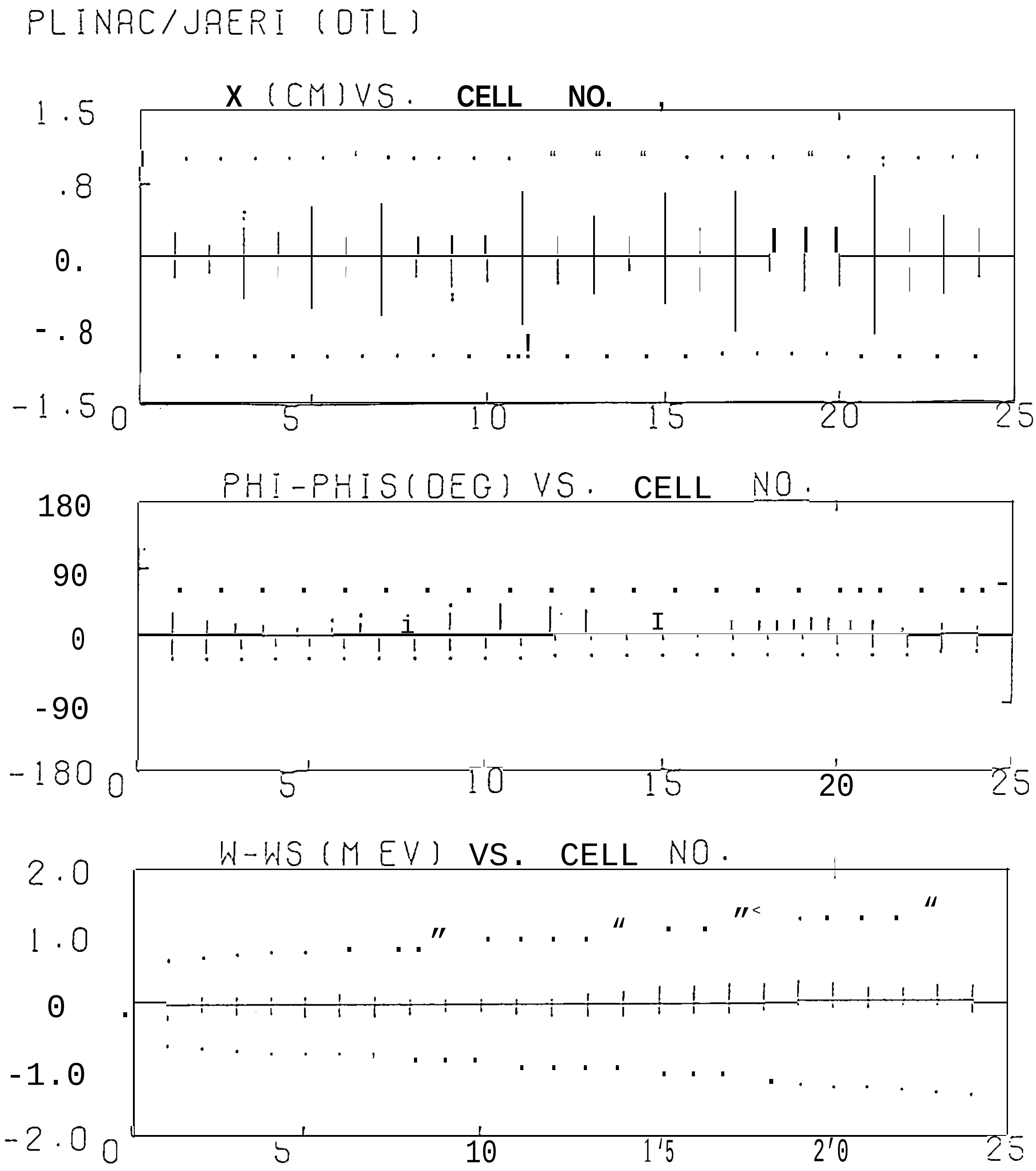


Fig. 3 Schematic layout of the Engineerlng Test Accelerator



RFQ Beam Dynamics Calculation with PARMTEQ

Fig. 4 An example of the preliminary design calculation for RFQ



DTL Beam Dynamics Calculation with PARMILA

Fig. 5 An example of the preliminary design calculation for DTL

Intense Proton Linear Accelerator Program

(Oct. 16, 1990)

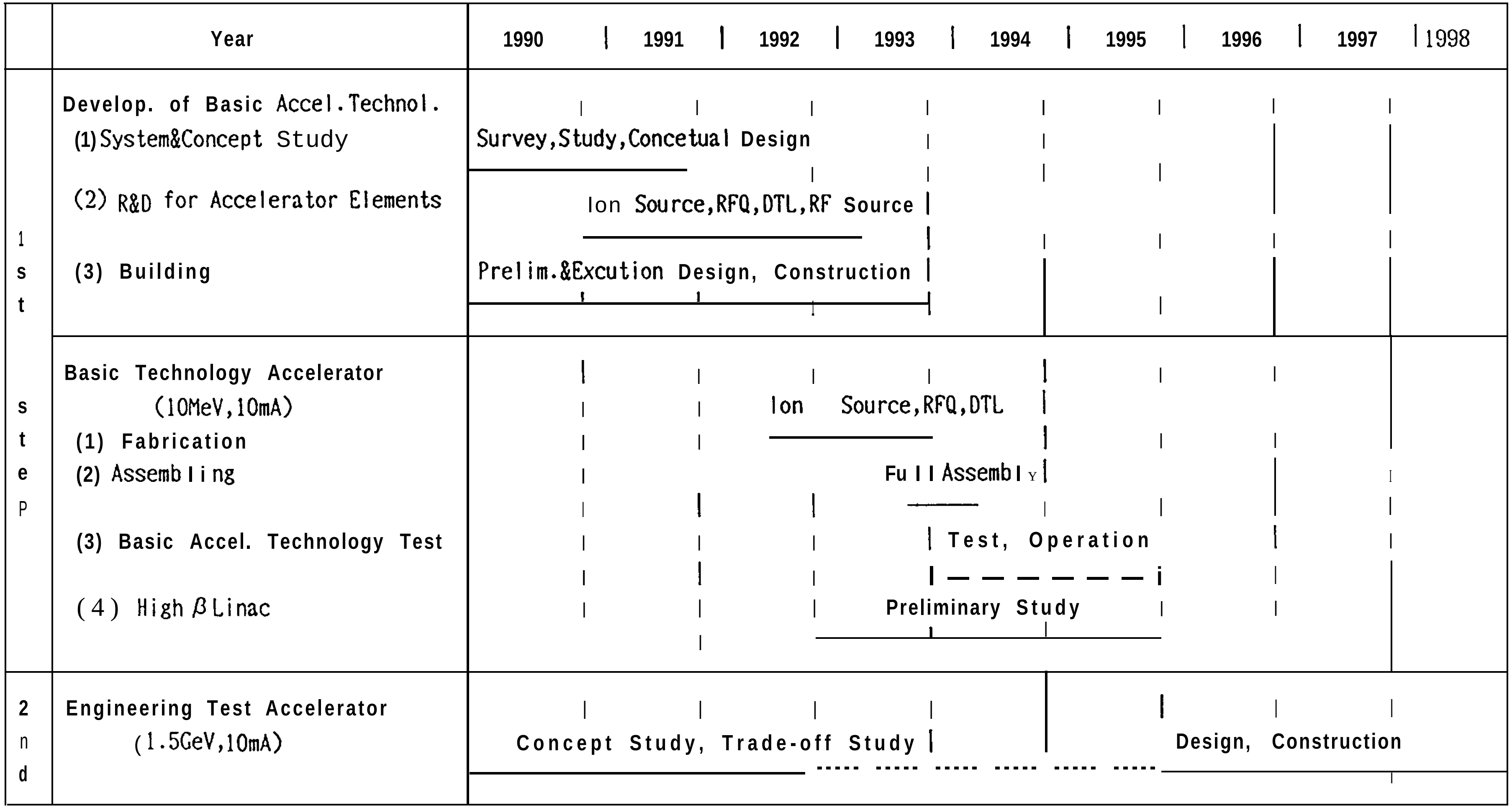


Fig. 6 Timeschedule of intense proton linear accelerator program