FN-120
0100

Parameters of the NAL 200 BeV Accelerator*

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Contents

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Brookhaven

I. MAIN ACCELERATOR

A. Principal Features of Main Accelerator

1. Final Energy	200 BeV (400-500 BeV)
2. Energy Resolution $\Delta E/E$	0.01%
3. Intensity	5×10^{13} protons/pulse (1.5×10^{13} protons/sec)
4. Radius (circumference/2π)	1 km (3281 ft)
5. Magnetic Radius	2453 ft (747.8m)
6. Circumference	20614 ft (6283 m)
7. Lattice Type	Separated-function with matched long straight sections
8. Injection Energy	10 BeV
9. Space Charge Limit	3×10^{14} protons
10. Betatron Oscillation Wave Number ν_x, ν_y	$\sim$20.25
11. Synchrotron Oscillation Wave Number ν_s	0.002
12. Transition Kinetic Energy	17.4 BeV
13. Rise Time	1.6 sec
14. Flat-Top Time	1 sec
15. Repetition Rate	
a. without flat-top	20 pulses/min
b. with 1 sec flat-top	15 pulses/min
16. Duty Factor (macroscopic)	0-25%
17. Beam Emittance (200 BeV)	
a. Vertical	0.009π cm-mrad
b. Horizontal	0.023π cm-mrad

B. Lattice Structure of Main Accelerator

1. Lattice Type	Separate-function with matched long straight sections
2. Standard Cell (or Normal Cell) (C)	
a. Length of bending magnets (B1 and B2)	19 ft 11 in (6.07 m)
b. Length of cell quadrupole magnet (QF and QD)	7 ft (2.13 m)
c. Length of minimum separation between magnets (S)	1 ft (0.305 m)
d. Length of short straight section (SS)	6 ft 11 in (2.11 m)

e. Cell Structure — (QF)SS(B1)S(B1)S(B2)S(B2)S-(QD)SS(B2)S(B2)S(B1)S(B1)S (8 bending magnets - 4 x B1 and 4 x B2) (2 quardupole magnets - QF and QD)

f. Total length of cell — 195 ft.2 in.(59.49 m)

g. Total number of standard cells — 84

3. Cell with Medium Straight Section (M)

a. Length of medium straight section (MS) — 48 ft. 9 in.(14.86 m)

b. Cell structure — (QF) MS(B1)S(B1)S(QD)SS(B2)S(B2) S(B1)S(B1)S

c. Total length of cell — 195 ft. 2 in.(59.49 m)

d. Total number of cells with MS — 6

4. Cell with Matched Long Straight Section (L)

a. Length of end matching quadrupole magnet (QFE and QDE) — 3 ft. 10 in.(1.168 m)

b. Length of outer matching quadrupole magnet (QFOand QDO) — 9 ft. 9 in.(2.972 m)

c. Length of inner matching quadrupole magnet — 11 ft.10.85 in.(3.628 m)

d. Length of end straight section next to QFE(ES) — 31 ft.(9.449m)

e. Length of end straight section next to QDO (OS) — 10 ft. 1 in. (3.07 m)

f. Length of separation between outer and inner matching quadrupole magnets (TS) — 4 ft.10.44 in.(1.484 m)

g. Length of long straight section (LS) — 169 ft.4.68 in.(51.63 m)

h. Cell structure — (QFE) ES(B1)S(B1)S(B1)S(QFO)-TS(QDI)LS(QFI)TS(QDO)OS(B2)S(B2)S(B2)S(B2) S (QDE)SS(B2)S-(B2)S(B1)S(B1)S

i. Total length of cell — 508 ft.2.25 in.(154.9 m)

j. Total number of cells with LS — 6

5. Superperiod

a. Structure — C•C•C•C•C•C•C C•C•L•C•C•M•-C•C•C

b. Total length of superperiod — 3435 ft.8.25 in.(1047.2 m)

c. Total number of superperiod — 6

6. Orbit Functions
   a. Betatron wavelength — 310.3 m
   b. Betatron amplitude function β
      Normal cells and medium straight section cells
      β_x (max.) — 98.8 m
      β_z (max.) — 98.9 m
      Long straight section cells
      β_x (max.) — 115.2 m
      β_z (max.) — 114.9 m
   c. Horizontal orbit deviation per unit momentum deviation $\Delta p/p$ (X_p)
      Normal cells (max.) — 5.10 m
      Medium-straight section cell (max.) — 4.96 m
      Long-straight section cell (max.) — 3.72 m
      Average — 2.61 m
   d. Revolution period
      injection — 21.04 μsec
      final energy (200 BeV) — 20.96 μsec

C. **Magnet System of Main Ring**

1. **Rise Time** — **1.6 sec**
2. Flat-Top Time — 1.0 sec
3. Bending Magnets
   a. Type B_1 magnets
      i. Number of units — 378
      ii. Length — 19 ft. 11 in. (6.07 m)
      iii. Aperture — 1.5 in. (high) x 5 in.
      iv. Injection field — 486 G (10 BeV)
      v. Peak field — 8.96 kG (200 BeV) 17.88 kG (400)
      vi. Number of turns of coil — 12
      vii. Current — ~2300 A (200 BeV) ~5000 A (400)
   b. Type B_2 magnets
      i. Number of units — 396
      ii. Length — 19 ft. 11 in. (6.07 m)
      iii. Aperture — 2 in. (high) x 4 in
      iv. Injection field — 486 G (10 BeV)
      v. Peak field — 8.96 kG (200 BeV) 17.88 kG (400)
      vi. Number of turns of coil — 16
      vii. Current — ~2300 A (200 BeV) ~5000 A (400)
4. Standard Cell Quadrupole Magnets
   a. Number of units — 180
   b. Length — 7 ft. (2.13 m)
   c. Aperture — 2 in. (high) x 5 in.
   d. Injection field gradient — 6.81 kG/m
   e. Peak field gradient — 125.6 kG/m (200 BeV) 250.5 kG/m (400 BeV)
5. Matching Quadrupoles
   a. Number of units
      i. Outer matching quadrupoles — 12
      ii. Inner matching quadrupoles — 12

iii. **End matching quadrupoles** 12

b. **Length**

i. **Outer matching quadrupoles** (QFO, QDO) 9 ft. 9 in. (2.97 m)

ii. Inner matching quadrupoles (QFI, QDI) 11 ft. 10.85 in. (3.63 m)

iii. End matching quadrupoles (QFE, QDE) 3 ft. 10 in. (1.17 m)

c. Peak field gradient 125.6 kG/m (200 BeV)
250.5 kG/m (400 BeV)

6. Correction Magnets

a. Closed-Orbit deflecting magnets, vertical and horizontal

i.	Peak field	$\pm$ 3 kG
ii.	Length of each unit	1 ft.
iii.	Number of units	1 each per cell
iv.	Total number of units	192

b. Trimming quadrupoles

i.	Field gradient	$\pm$ 7 kG/m
ii.	Length of each unit	0.5 ft.
iii.	Number of units	2 per cell
iv.	Total number of units	192

c. Sextupoles

i.	Field gradient	$\pm$ 2000 kG/m^2
ii.	Length of each unit	1 ft.
iii.	Number of units	2 per cell
iv.	Total number of units	192

7. Magnet Weight

a. Bending Magnet, (B1 or B2) each unit 13.3 tons

b. Quadrupole Magnet, (QF, QD) each unit 3.55 tons

c. Inner matching quadrupole magnet (QFI, QDI), each unit 1.73 tons

d. Outer matching quadrupole magnet (QFO, QDO), each unit 1.50 tons

e. End matching quadrupole magnet (QFE, QDE), each unit 0.45 ton

f. Total Weight (of all units)

i. Core Steel 8900 tons

ii. Copper 850 tons

8. Power Supply Rectifier-Inverters (no rotating machine)

a. Inductance of magnet circuit 5.3 H

b. Resistance of magnet circuit 6.0 Ω at 40°C

9. Power Input

a.	Peak	53 MW
b.	Mean	16 MW
c.	Reactive voltamperes	approx. 10 MVAR (max.)
d.	Total RMS voltamperes	28 MVA

10. Center of Magnet Above Floor Level 3 ft.

D. Magnet Support, Adjustment, Foundation, Survey and Enclosure	
1. Magnet Support and Adjustment	
a. Support	Magnets supported at ends by adjustable pedestals. No support beams.
b. Adjustment	Jacks equipped with gears which can be adjusted by coupling to remote-controlled traveling device.
2. Foundation	Slab on ground. No piles.
3. Survey	Cross wires and position pickups attached to pedestal. Twelve reference monuments one placed at each end of the long-straight sections. One of the piers at each long-straight section will include an inverted pendulum attached to bed rock.
4. Enclosure	
a. Size	
i. Standard sections	10 ft. diameter horseshoe shaped precast concrete sections, 9 ft. wide at base.
ii. Long-Straight sections A and B	16 ft. 6 in. high x 20 ft. wide rectangular poured-in-place concrete.
iii. Long-Straight sections, C, D, E, and F and Medium-Straight sections	12 ft. diameter horseshoe shaped precast concrete sections, 11 ft. wide at base.
E. Vacuum System of Main Accelerator	
1. Vacuum Chamber	
a. Material and wall thickness	≤50 mil stainless steel
b. Size	
i. Type B1 magnets	3.5 cm x 12 cm (inside dim.)
ii. Type B2 magnets	5 cm x 10 cm oval (inside dim.
c. Length	
i. Type B1 and B2 magnets (as integral unit of each magnet)	21 ft.
ii. Quadrupole magnets (as integral unit of each magnet)	8 ft.
2. Pumping System	
a. Number of sputter ion pumps	
i. Vacuum envelope (50 1/sec)	Approx. 400
ii. RF cavities (200 1/sec)	16
iii. Long straight sections (100 1/sec)	12
iv. Special tanks (2000 1/sec)	3
b. Number of roughing pump stations	6 permanent stations and portable units

F. Radio Frequency System of Main Accelerator

1. Injection Energy	10 BeV (8-10 BeV)
2. Final Energy	200 BeV (400-500 BeV)
3. Main Accelerator Magnet Rise Time	1.6 sec
4. Acceleration Cycle Time (acceleration in 2 stages)	
a. Front pedestal (no acceleration)	0.8 sec (0-0.8 sec)
b. Rise time from 10-16.3 BeV	0.1 sec (0.8-0.9 sec)
c. Rise time from 16.3-200 BeV	1.5 sec (0.9-2.4 sec)
d. Duration of flat-top	1.0 sec (2.4-3.4 sec)
e. Fall-off time	0.6 sec
f. Acceleration cycle time	
i. Without flat-top	3 sec
ii. With flat-top	4 sec
5. $\dot{B}$, Average	5.69 kG/sec
6. Synchronous Phase - Programmed	50^{o} maximum
7. Peak RF Voltage per Turn	16 x .217 = 3.47 MV
8. Energy Gain per Turn	2.66 MeV
9. Average Circulating Beam Current	0.382 A
10. Harmonic Number	1120
11. Injection Frequency	53.24 MHz
12. Final Frequency	53.44 MHz
13. Relative Frequency Change	0.37%
14. R_b (beam shunt resistance)	7 MΩ
15. Total Number of Accelerating Cavities	16
16. Length of Individual Cavity	68 in.
17. Required Straight Section Length	91 ft.
18. Orbit Frequency Range	47.54-47.71 kHz
19. Total RF Power Input	
a. Peak	2 MW
b. Mean	1 MW
20. Total RF System Stored Energy	12 J

II. BOOSTER SYNCHROTRON AND BEAM TRANSFER PARAMETERS

A. General

1. Summary Booster Parameters

a.	Output energy	10 BeV
b.	Input energy	0.2 BeV
c.	Transition energy	4.48 BeV
d.	Beam intensity	3.8×10^{12} protons/pulse
e.	Orbit radius	75 m
f.	Magnetic radius	43.7 m
g.	Focusing type	Alternating gradient
h.	Lattice type	FOFDOOD, combined function
i.	Cycling rate of magnet	15 Hz
j.	Guide field at injection	490 G
k.	Peak magnetic guide field	8.32 kG
l.	Betatron oscillation wave number	$\nu_x = 6.75$ $\nu_z = 6.75$
m.	Number of lattice cells	24 (identical)
n.	Injector accelerator	Drift-Tube Linac

2. Intensity Parameters

a.	Proton beam intensity, nominal	3.8×10^{12} protons/pulse
b.	Lowest calculated space charge limit, i.e., incoherent transverse space charge defocusing, nominal	8.6×10^{12} protons/pulse
c.	Linac injector beam intensity, nominal	75 mA
d.	Typical injection operational mode	50 mA, 5 turns
e.	Charge injected into main ring, nominal (13 booster cycles)	5.0×10^{13} protons

3. Beam Transfer Parameters

a.	Injector transverse emittance area	π cm-mrad
b.	Transverse emittance area, after stacking, nominal	
	i. horizontal	5π cm-mrad
	ii. vertical	2π cm-mrad
c.	Booster transverse emittance area, at ejection, nominal	
	i. horizontal	0.3π cm-mrad
	ii. vertical	0.12π cm-mrad
d.	Injector, momentum spread after debuncher, $(\Delta p/p)$	$\pm 1.1 \times 10^{-3}$

e.	Booster, momentum spread for bunched beam, at injection	$\pm 2.5 \times 10^{-3}$
f.	Bunching factor	0.44
g.	Longitudinal phase space area, at injection	2.22 eV-sec
h.	Bucket area, at injection	3.00 eV-sec
i.	Booster momentum spread, at ejection	$\pm 0.9 \times 10^{-3}$
j.	Booster bunching factor, at ejection	0.14

B. Further Booster Parameters

1. Orbit Parameters

a.	Betatron wavelength, horizontal	69.8 m
b.	Betatron amplitude function, β gradient magnets	
i.	β F (max), horizontal	30.7 m
ii.	β F (max), vertical	11.6 m
iii.	β D (max), horizontal	15.5 m
iv.	β D (max), vertical	22.6 m
c.	Horizontal orbit deviation per unit momentum deviation $\Delta p/p$ (X_p)	
i.	F	2.9 m
ii.	D	2.1 m
d.	Phase advance per cell	0.28 (2π)
e.	Synchrotron oscillation wave number, (max.)	0.1
f.	Revolution period	
i.	at injection	2.78 μsec
ii.	at ejection	1.58 μsec

2. Cell Structure

a.	Cell length	19.63 m
b.	Number of gradient magnets per cell	4
c.	Length of long-straight section	5 m
d.	Length of short-straight section	2 m
e.	Length of intermagnet straights	0.6 m
f.	Circumference factor	1.72

3. Aperture Requirements

Vacuum envelope, internal dimensions, approx. elliptical

a.	Gradient magnets	
i.	F, horizontal	5.5 in.

	ii.	F, vertical	1.75 in.
	iii.	D, horizontal	4.0 in.
	iv.	D. vertical	2.5 in.
b.	Long-straight section		
	i.	Horizontal	2.25 in.
	ii.	Vertical	2.5 in.
c.	Magnet gap		
	i.	F, vertical	2.25 in.
	ii.	D, vertical	3.0 in.

C. Magnet System

1.	Rise Time		1/30 sec
2.	Combined Function Magnets		
	a.	Number of magnets	48 (D), 48 (F)
	b.	Length of magnets (effective)	9.4 ft. (2.86 m)
	c.	Aperture	
		i. F magnets	6.0 in. x 2.25 in.
		ii. D magnets	4.5 in. x 3.0 in.
	d.	Cross-section of magnets	25 in. x 18 in.
	e.	Magnetic Field	
		i. at injection	490 G
		ii. peak field	8.3 kG
	f.	Magnet Profile Parameter, $\lvert B_0'/B_0 \rvert$	
		i. F magnets	2.36 m^{-1}
		ii. D magnets	2.48 m^{-1}
3.	Trimming Magnets		
	a.	Number of tune correcting quadrupoles	24
	b.	Number of skew quadrupoles	48
	c.	Number of correcting sextupoles	24
	d.	Number of closed-orbit deflectors	48
4.	Magnet Weight - Total		
	a.	Core steel	500 tons
	b.	Copper	50 tons
5.	Current Density		4000 A/in.^{2}
6.	Power Losses		
	a.	Total AC	1.1 MW
	b.	Total DC	1.9 MW
7.	Stored Energy		
	a.	Magnet	1.6 MJ
	b.	Inductors	1.6 MJ
	c.	Capacitors	0.7 MJ

D.	Resonant Magnet Power Supply		
	1.	Magnet excitation	sinusoidal by biased resonant circuit
	2.	Numbers of Resonant Cells	24
	3.	Magnet Current	
		a. At injection	124 A
		b. Peak	2100 A
		c. Bias	1100 A
	4.	Magnet Inductance	0.7 H
	5.	Magnet Coil DC Resistance	0.8 Ω
	6.	Peak AC Power Supply Voltage	2.9 kV
	7.	AC Voltage per Cell (rms)	2030 V
	8.	Maximum Voltage to Earth	1600 V
	9.	Capacitance per Cell	7260 μF
	10.	Choke Inductance per Cell	0.03 H
	11.	Peak Magnet Stored Energy	1.6 MJ
	12.	Peak Capacitor Stored Energy	720 kJ
	13.	Total Choke Stored Energy	1.64 MJ
	14.	AC Power Losses	1.1 MW
		a. Magnets	510 kW
		b. Chokes	510 kW
		c. Capacitors	91 kW
		DC Power Losses	1.9 MW
		a. Magnets	980 kW
		b. Chokes	980 kW
		Power Supply Rating	
		a. AC	1.2 MW
		b. DC	2.0 MW
E.	Vacuum Chamber		
	1.	Outside Dimensions	
		a. F-magnet	6.0 in. x 2.25 in.
		b. D-magnet	4.5 in. x 3.0 in.
	2.	Aperture	
		a. F-magnet	5.5 in x 1.75 in.
		b. D-magnet	4.0 in. x 2.5 in.
		c. RF section	2.2 in. x 2.4 in.
F.	Radio Frequency System		
	1.	System Parameters	
		a. Injection Energy	200 MeV
		b. Final Energy	10 BeV
		c. Rise Time	1/30 sec
		d. Repetition Rate	15 Hz
		e. Synchronous Phase - Programmed	70° maximum
		f. Peak RF Voltage	850 kV
		g. Energy Gain per Turn (max)	0.76 MeV
		h. Harmonic Number	84
		i. Radio Frequency	30.26-53.24 MHz

j.	Frequency Ratio	1.76 to 1
k.	Momentum Spread at Injection ($\Delta p/p$) Inj	$\pm 1.1 \times 10^{-3}$
l.	Number of Accelerating Cavities	18
m.	RF Power	
i.	Peak Total	0.7 MW
ii.	Average (Booster on only for main accelerator injection)	50-70 kW
	(Booster on continuously)	250 kW
iii.	Peak Power to Beam	0.3 MW

2. Accelerating Structure Parameters

a.	Cavity length	2.4 m
b.	Total Length of Accelerating Structure	43 m
c.	Total Volume of Ferrite	2 m^3
d.	Total Weight of Ferrite	22,000 lb.
e.	Cavity Peak Voltage (across 2 gaps/cavity)	48 kV
f.	Axial Field Strength in Gap	0.32 MV/m
g.	Cavity RF Current (at current maximum)	1200 A
h.	Cavity Z_o (tapers from 80 Ω at gap to 20 Ω at center)	60 Ω
i.	RF Stored Energy/Cavity at Maximum Voltage	0.03 J

3. Ferrite Tuner Parameters

a.	Number of tuners per Cavity	2
b.	Ferrite Density	5 gm/cm^3
c.	Ferrite Weight	1200 lb.
d.	Ferrite Volume	110,000 cm^3
e.	Weight of Copper Cooling Rings	1250 lb.
f.	Resistance of Bias Circuit at 30 Hz, 23° C	8 $\mu\Omega$
g.	Maximum H_{dc}	30 kA/m
h.	Minimum H_{dc}	5 kA/m
i.	H_{rf} (at location of ferrite)	780 A/m
j.	Ferrite μ_Δ at Injection	7.2
k.	Ferrite μ_Δ at Ejection	1.5

III. LINAC INJECTOR

A. Energy

1. Input Energy	0.75 MeV
2. Output Energy	200.30 MeV
3. Output Energy Spread, ΔE	
a. Before debuncher	$\pm$ 1 MeV
b. After debuncher	$\pm$ 0.4 MeV

B. Beam Characteristics

1. Peak Beam Current	75 mA
2. Beam Pulse Length	100 μsec
3. Pulse Rate	15/sec
4. Duty Cycle (max)	0.15 %
5. Beam Emittance at 200 MeV (each transverse mode)	0.5 π to 1.0 π cm-mrad

C. RF Characteristics

1. RF Frequency	201.25 MHz
2. RF Pulse Length	300 μsec
3. Repetition Rate (max)	15 pps
4. RF Duty Factor	0.5 %
5. Peak RF Excitation Power	22 MW
6. Average RF Excitation Power	110 kW
7. Total Peak RF Power (at 75 mA)	37 MW

D. Physical Characteristics

1. Number of Accelerating Cavities	9
2. Total Length Including Drift Space between Cavities	145.8 m
3. Number of Drift Tubes	286
4. Aperture	
a. Input at Tank 1	2 cm
b. Output at Tank 9	4 cm

IV. PRE-INJECTOR

1.	Number of Pre-Injectors	2
2.	Voltage	750 kV
3.	Voltage Stability	$\pm$ 0.05%
4.	Ion Beam Current	220-300 mA
5.	Beam Pulse Length	30-100 μsec
6.	Pulse Repitition Rate	15/sec
7.	Beam Emittance	5πcm-mrad
8.	Power Supply Type	Cockroft-Walton
9.	Accelerator Tube Length	11.8 in. (30 cm)
10.	Accelerator Tube Aperture	2.5 in.

V. MONITOR AND CONTROL SYSTEM

A. Control Center

1. Functions
   a. Data logging, data processing, data analysis and information display
   b. Transmitting commands of control operations to various components of accelerator system — A high speed computer with sufficiently large memory is provided to perform most of this task. However, the control is so designed such that accelerator can be operated manually independent of the computer.

2. Control Panels in Control Center
   a. Subcontrol panels
      i. Main accelerator subcontrol panel
      ii. Booster subcontrol panel
      iii. Linac subcontrol panel
      iv. Experimental beam control subcontrol panel
   b. Master control desk — For the operation and supervision of the entire accelerating system, all the essential control functions and monitoring information are centered in one master control desk whose controls have priority over all the subcontrol systems.

B. Information Transmission System

1. Time-Sharing Multiplex System
   a. Coverage of system
      i. Main accelerator (except RF)
      ii. Booster synchrotron
      iii. Extracted beam area
   b. Number of monitoring and control data

	Main Accel.	Booster	Linac*
i. Average data transmission distances (ft)	6000	1200	600
ii. Number of status points	4685	800	72
iii. Number of on-off control	711	155	96
iv. Number of analog control	504	122	170

	Main Accel.	Booster	Linac*
v. Number of analog monitoring	5564	966	177
vi. Number of video monitoring	1211	23	47

*These figures do not include the approx. 1000 analog and status points from Linac to its local data station.

2. Direct-Wire Transmission System
   a. Coverage of system
      i. Linac injector and pre-accelerator
      ii. RF system of main accelerator
      iii. Beam extraction system
      iv. Beam transfer system between booster and main accelerator
      v. Radiation protection and personnel access circuit
      vi. Extracted beam area (some components)
      vii. Booster RF
      viii. Beam pick-up
      ix. Converter control

C. Data Collection Stations

1. Multiplex System, Number of Data Collection Stations

a. Main accelerator	24
b. Booster synchrotron	4
c. Extracted beam areas	6

2. Direct-Wire System, Number of Data Collection Stations

a. Linac and pre-accelerator	1
b. RF system of main accelerator	1
c. Beam extraction system	1
d. Beam transfer (booster-main accelerator)	1
e. Booster RF	1
f. Converter control	1

VI. BEAM EXTRACTION SYSTEM

A. Fast and Slow Extraction Systems

Both systems will have the same magnet system but different exciting mechanisms. Fast extraction system using a kicker coil can extract beam in a single turn giving a burst length of 20 μsec.. Using the resonant extraction scheme, the slow extraction system extracts beam with constant intensity during flat top (up to 1 sec duration).

B. Extraction Magnet System

a. Hyper-thin-system deflector, 2 mil septum deflector, 200 in. long electrostatic beam deflection 0.1 mrad.

b. 20 - 30 mil septum, 200 in. long magnet system, beam deflection 0.4 mrad.

c. 200 - 400 mils septum, 200 in. long magnet system. beam deflection 4 mrad.

d. 0.5-2 in. septum, 550 in. long magnet system, beam deflection 19 mrad.

C. Extraction Efficiency

Expected extraction efficiency $\geqq$ 99%.

D. Extracted Beam

One extracted proton beam feeding into a switchyard where it can be switched into two target stations.

VII EXPERIMENTAL FACILITIES AND EQUIPMENT

A. External Beam Transport

1. Extracted Proton Beams(EPB)

Extracted proton beam from straight section A is fed into a switchyard where it is split into beams, denoted "AB" and "C".

Provision will be made for a number of additional extraction points to which future facilities such as storage rings, internal beam bypasses, or additional target areas may be joined without major accelerator shutdown. Reserved long straight sections with beam outlet snout in the tunnel are required for the present.

B. External Beam Target Stations

1. Target Station Arrangement

Two target stations in series in EPB branch "AB":
1) Target station A will be a thin target station for "low" energy and low intensity secondary beams; p-p interactions can be studied at station A with the use of a hydrogen target in the primary proton beam.

2) Target station B will be a major, "multi-beam" target station in which a number of simultaneously operated secondary beams will be produced. One target station in EPB branch "C":

Target station C, which will be a major target station similar to station B.

2. Target Station Buildings

Shielded target stations with a total area of $\sim 10^5$ sq ft. There will be beam lines serving a number of locations for experiments: about 10 experiments will be able to run at the same time.

C. Internal Beam Target Station

Internal target station (I) at straight section B. An enlarged section of main ring enclosure. This station can be modified in the future to become a second EPB extraction station. Intensity limit: 10^{12} protons/sec

D. Experimental Areas

Enclosed areas totaling approximately 100,000 square feet at the four target areas I, A, B, C.

Paved areas totaling approximately 80,000 square feet at the four target areas, to be partly covered by temporary housings for particular beams and experiments.

Total power demand: 60 MW
13.8 kV power distribution: 90 MW

E. Equipment

Not yet specified *

* A preliminary specification, of a list of equipment to be provided, will be developed at the NAL Summer Study program in June-August, 1968.

F. Typical Secondary Beams from External Targets (10^{13} protons/sec)

Particle	Momentum GeV/c	$\Delta p/p$ $\pm$ %	Intensity Sec^{-1}
π	25	1	10^8
K	50	0.1	10^6
π	150	0.1	10^7
P	200	< 0.1	10^{13}
μ	40	10	10^8
ν	15	10	10^8

V111. RADIATION PROBLEMS

A. Shielding	Sufficient shielding for full-scope operation (1.5 x 10^{13} p/sec 400 BeV)
1. Main Ring	a. Hot area* 30 ft of dirt b. Quiet area 20 ft of dirt *The structure of the hot area will have the capability of supporting 40 ft of dirt.
2. Linac	
3. Booster	
4. Experimental Area (reduced scope)	\$12 x 10^6 worth of shielding is tentatively planned for.
B. Remote Handling	
1. In Main Enclosure	a. Magnets in hot areas can be removed and replaced by remotely-controlled handling truck. b. Personnel can enter hot areas for inspection in lead-shielded truck. c. Remotely-controlled trucks are servo-guided by rail above enclosure floor on magnet side of aisle. d. Magnet position adjusted by remotely-controlled truck under control from main control room.
2. In Other Areas	
C. Radiation Damage	
D. Residual Radiation	

IX. PHYSICAL PLANT

A. General Parameters

1. Main Accelerator	Sec (I)
2. Booster Synchrotron	Sec (II)
3. Linac Injector	Sec (III)
4. Preinjector	Sec (IV)
5. Experimental Areas	Sec (VII)
6. Support Area	
a. Design population	
i. Total number	2000
ii. Directorate	55
iii. In-house research	395
iv. Visitor research	345
v. Accelerator operation and development	455
vi. Technical support	405
vii. Support services	345
b. Design philosophy	All functions, except for shops and warehouse, are concentrated in a support center, close to Linac, Booster and Main Accelerator.

B. Parameters for Structural Planning

1. Foundations - Allowable Soil Bearing Capacities	
a. Clay soil	2 tons/sq. ft.*
b. Bed rock	17 tons/sq. ft*
	*these values have a safety factor of 3.
2. Design Loadings	
a. Floor loads	In accordance with ASA A58.1
b. Wind load	
i. Structure at height of 30 ft.	95 miles/hour
ii. Structure at height other than 30 ft.	$p = .00256V^2{C_h}^2 C_s$ p = wind pressure (lbs/sq. ft.) v = wind velocity (miles/hr.) C_h = height factor = $\left(\frac{H}{30}\right)^{1/7}$

	C_s = drag coefficient or shape factor
c. Roof load	30 lbs. /sq. ft. of horizontal projection, including snow, sleet, construction and repair loads.
d. Earthquake loads	Seismic probability zone I.

C. Civil Engineering Parameters

1. Grading and Drainage	
a. Shielding fill	
i. Overstandard housing sections and medium straight sections	20 ft.
ii. Over long straight sections	30 ft.
b. Minimum load protection	
i. Main ring, booster, linac, experimental and staging areas, central utility plant and support area	100 year frequency flood.
ii. Major access roads and parking areas	25 year frequency flood.
iii. Minor roads and areas subject to minimum flood damage losses	10 year frequency flood.
2. Roads and Paved Areas	
a. Vehicle ratio	1 automobile/employee
b. Parking facilities	resident population long and short. term visitors, service vehicles, overlap during shift changes.
c. Pavement design	
i. Roads, bridges, culverts, experimental area paving	A. A. S. H. O. H20-S16 truck loads
ii. Passenger vehicle parking	6,000 lb. (max.) single axle load.
3. Water Supply	
a. Potable water	110 gallons/day/person
b. Cooling water	2000 gallons/minute makeup at 100 parts/million calicum carbonate hardness.

c. Fire protection	maximum fire flow of 1750 gallons/minute for 7 hours in support area. Maximum flow of 1000 gallons/minute for main ring.
d. Irrigation	370 gallons/minute for 9 hours/day during 4 hottest months

4. Waste Water Disposal

a. Treatment	Tertiary, for combined domestic waste and cooling-tower blow down.
b. Domestic waste	100/gallons/day/person.
c. Cooling tower blow down	500 gallons/minute. (25% of cooling water makeup)
d. Infiltration	2000 gallons/day/diameter-inch mile of sewer. Total, 125 gallons/minute.

D. Mechanical Engineering Parameters

1. Outdoor Design Conditions

	Dry Bulb (^{o}F)	Wet Bulb (^{o}F)
Winter	-9	---
Summer	93	78

2. Indoor Design Conditions

	Dry Bulb (^{o}F)		Relative
	Summer	Winter	Humidity
a. Linac			
Pre-Injector	$75^{o} \pm 1^{o}$	$75^{o} \pm 1^{o}$	30/50% ± 5%
Housing	$75^{o} \pm 4^{o}$	$75^{o} \pm 4^{o}$	50% ± 5%
Equipment Bay	$75^{o} \pm 5^{o}$	$70^{o} \pm 5^{o}$	50% ± 10% (summer)
b. Booster Synchrotron			
Housing	$75^{o} \pm 4^{o}$	$75^{o} \pm 4^{o}$	50% ± 5%
Gallery	$75^{o} \pm 5^{o}$	$70^{o} \pm 5^{o}$	50% ± 10% (summer)
c. Main Accelerator			
Housing	60^{o} to 105^{o}	60^{o} to 105^{o}	
RF & power supply	$80^{o} \pm 5^{o}$	$70^{o} \pm 5^{o}$	50% ± 10% (summer)
Utility buildings	10^{o} above ambient	$60^{o} \pm 5^{o}$	

	Dry Bulb ($^{\circ}$F) Summer	Dry Bulb ($^{\circ}$F) Winter	Relative Humidity
d. External beam area			
Transport housing	60° to 105°	60° to 105°	
Straight section A	60° to 105°	60° to 105°	
Exper. Bldgs.		$65^{\circ} \pm 5^{\circ}$	
e. Internal beam area			
Transport housing	60° to 105°	60° to 105°	
Straight section B	60° to 105°	60° to 105°	
IPB Bldg.		$65^{\circ} \pm 5^{\circ}$	
f. Support area			
Offices and light Laboratories	$75^{\circ} \pm 5^{\circ}$	$70^{\circ} \pm 5^{\circ}$	50% $\pm$ 10%
Shops	$80^{\circ} \pm 5^{\circ}$	$70^{\circ} \pm 5^{\circ}$	50% $\pm$ 10%
Warehouse		$60^{\circ} \pm 5^{\circ}$	

E. Electrical Power Parameters

1. Main Accelerator
   - a. Pulsed power-magnet supply
     - i. Peak pulsed magnet power — 54 MW
     - ii. Over-all power demand (RMS) — 32.55 MW
     - iii. Distribution voltage — 34.5 KV
   - b. Conventional power
     - i. Connected load — 12 MVA
     - ii. Demand load — 8 MVA
     - iii. Distribution voltage — 13.8 KV
2. Booster Synchrotron
   - a. Machine components
     - i. Connected load — 10.5 MW
     - ii. Demand load — 9.5 MW
     - iii. Distribution voltage — 13.8 KV
   - b. Conventional power
     - i. Connected load — 2 MW
     - ii. Demand load 1.5 MW — 1.5 MW
     - iii. Distribution voltage — 13.8 KV
3. Linac
   - a. Machine components
     - i. Connected load — 3.5 MW
     - ii. Demand load — 3 MW
     - iii. Distribution voltage — 13.8 KV
   - b. Conventional power
     - i. Connected load — 1.25 MW
     - ii. Demand load — 1 MW
     - iii. Distribution voltage — 13.8 KV
4. Experimental Areas
   - a. Magnet power - non-pulsed
     - i. Connected load — 105 MW
     - ii. Demand load — 62 MW
     - iii. Distribution voltage — 13.8 KV

b. Conventional power	
i. Connected load	12 MW
ii. Demand load	8 MW
iii. Distribution voltage	13.8 KV
5. Support Facilities	
a. Conventional power	
i. Connected load	19.5 MW
ii. Demand load	13 MW
iii. Distribution voltage	13.8 KV
6. Total Power Demand	
a. 200 BeV	144 MW
b. 400 BeV	230 MW
7. Pulsed Power Load	
a. Maximum	54 MW*
b. Minimum (inverted power)	-28 MW*
	*Pulsed directly on 345 KV power grid
8. Reliability	1 to 2 momentary outages/year. One sustained outage every five years.
9. Voltage Regulation	
a. Normal daily variation	$\pm$ 3%
b. Maximum voltage drop	-10%
c. Transformer load tap changers	$\pm$ 7.5% range
10. Frequency	60 cycles $\pm$ .05%
11. Available Short Circuit Capacity (by 1972)	
a. 138 KV bus	4500 MVA (symmetrical)
b. 345 KV bus	18,000 MVA (symmetrical)

X. FUTURE PLANS

1. Increase of Peak Energy

   Up to 400-500 BeV mainly by increase of magnet power supply. Other modifications required include cooling system, injection, r.f. system, extraction, external beam handling and controls.

2. Increase of Intensity

   The formal space charge limit of 10^{14} protons per pulse can be increased by a factor of 2.5 by interposing a "supercharger," a 500 MeV synchrotron, between the 200 MeV Linac and the booster.

3. Expansion of Existing Experimental Area

   a. Addition of branches to secondary beams.
   b. Addition of new secondary beams of existing targets.
   c. Additional branches may be taken off the existing external proton beam, by moving the beam stop back and installing new branch points, transport enclosures, targets and experimental areas.

4. Addition of a Beam Bypass, Storage Rings and Colliding Beams

   At long straight-section B, the present internal target area, the full energy beam can be extracted and taken around a "beam bypass" to be reinjected in the ring at long straight-section D.

   A by-pass storage ring system is explored as a possible future facility for colliding beam experiment. Center-of-mass energies of 140 to 280 BeV are feasible. Radius of storage ring considered ranges between 50 and 100 m. A portion of the stacked beam in the storage ring is reinjected back into the main accelerator which is then operated D.C. as a storage ring. This way much greater luminosity in the colliding beam can be achieved. The energy of the stored protons in the storage ring varies from 20 to 100 BeV depending on the radius and on whether conventional or superconducting magnets will be used. The energy of the stored protons in the main accelerator operated D.C. can be as high as 250 BeV. (The power required operating D.C. at 250 BeV is equivalent to that of operating pulsed at 400 BeV.) An equivalent laboratory energy for the colliding beam of the order of 10^4 BeV is attainable. Under conditions at the space charge limit, storage ring current of the order of 1000 amperes is considered feasible with a corresponding luminosity of the order 10^{32} cm^{-2} sec^{-1}.

Energies of Bypass Storage Ring

	Kinetic Energy (BeV)		Center-of-Mass Energy (BeV)	Equivalent Laboratory Energy (BeV)*
	Beam 1	Beam 2		
NAL Accelerator	200	0	20	200
	400	0	28.3	400
CERN ISR	30	30	60	1,800
Bypass Storage Ring	200	25	141	10,000
	200	50	200	20,000
	200	100	283	40,000

*Energy of a proton giving the same center-of-mass energy in a collision with a stationary proton

It is also possible to provide concentric intersecting storage rings of the same radius as the main accelerator. Protons would be injected into the rings from the extracted beam associated with the external bypass. It can provide 200-200 BeV collisions, with an equivalent laboratory energy of 80,000 BeV. Slow acceleration might be carried out in it to proton energies of 1000 BeV.