SNS 100000000-PL0001-R13

SNS Parameters List

June 2005

A U.S. Department of Energy Multilaboratory Project

SPALLATION NEUTRON SOURCE

Argonne National Laboratory • Brookhaven National Laboratory • Thomas Jefferson National Accelerator Facility • Lawrence Berkeley National Laboratory • Los Alamos National Laboratory • Oak Ridge National Laboratory

SNS

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SNS PARAMETERS LIST

June 2005

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UT-BATTELLE, LLC
managing
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Argonne National Laboratory
Brookhaven National Laboratory
Thomas Jefferson National Accelerator Facility
Lawrence Berkeley National Laboratory
Los Alamos National Laboratory
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June 2005

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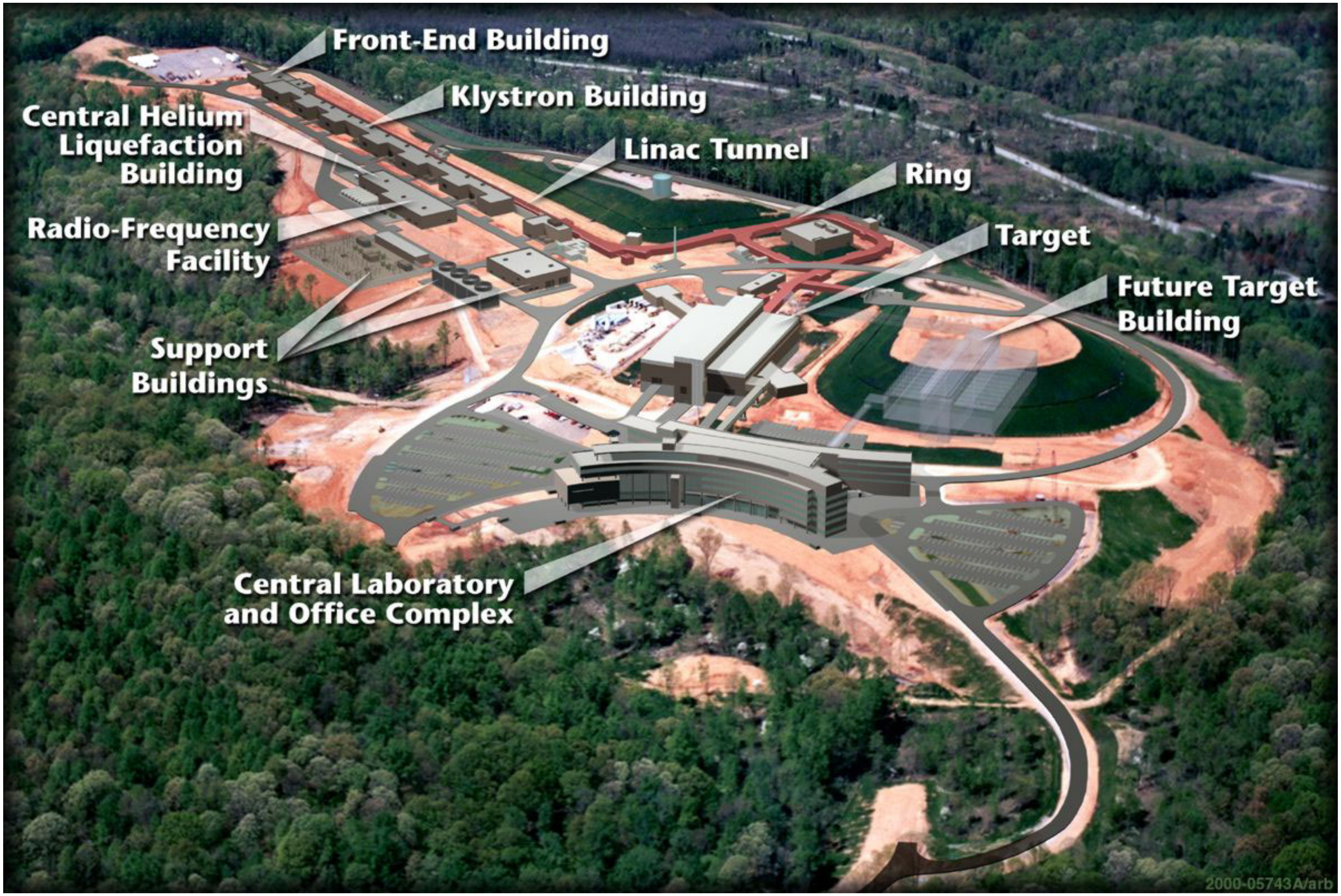

SNS Site Overlay

Spallation Neutron Source Primary Parameters

Proton beam power on target	1.4 MW
Proton beam kinetic energy on target	1.0 GeV
Average beam current on target	1.4 mA
Pulse repetition rate	60 Hz
Protons per pulse on target	1.5×10^{14} protons
Charge per pulse on target	24 μC
Energy per pulse on target	24 kJ
Proton pulse length on target	695 ns
Ion type (Front end, Linac, HEBT)	H minus
Average linac macropulse H- current	26 mA
Linac beam macropulse duty factor	6 %
Front end length	7.5 m
Linac length	331 m
HEBT length	170 m
Ring circumference	248 m
RTBT length	150 m
Ion type (Ring, RTBT, Target)	proton
Ring filling time	1.0 ms
Ring revolution frequency	1.058 MHz
Number of injected turns	1060
Ring filling fraction	68 %
Ring extraction beam gap	250 ns
Maximum uncontrolled beam loss	1 W/m
Target material	Hg
Number of ambient / cold moderators	1/3
Number of neutron beam shutters	18
Initial number of instruments	5

SNS Beam Evolution Parameters

	Front End		Linac					Ring			
	IS/LEBT	**RFQ**	**MEBT**	**DTL**	**CCL**	**SCL (1)**	**SCL (2)**	**HEBT**	**Ring**	**RTBT**	**Unit**
Output Energy	0.065	2.5	2.5	86.8	185.6	391.4	1000	1000	1000	1000	MeV
Relativistic factor □	0.0118	0.0728	0.0728	0.4026	0.5503	0.7084	0.875	0.875	0.875	0.875	
Relativistic factor □	1.00007	1.0027	1.0027	1.0924	1.1977	1.4167	2.066	2.066	2.066	2.066	
Peak current	47	38	38	38	38	38	38	38	9×10^{4}	9×10^{4}	mA
Minimum horizontal acceptance [g]			250	38	19	57	50	26	480	480	πmm mr
Output H emittance (unnorm., rms)	17	2.9	3.7	0.75	0.59	0.41	0.23	0.26	24	24	πmm mr
Minimum vertical acceptance [g]			51	42	18	55	39	26	480	400	πmm mr
Output V emittance (unnorm., rms)	17	2.9	3.7	0.75	0.59	0.41	0.23	0.26	24	24	πmm mr
Minimum longitudinal acceptance			4.7E-05	2.4E-05	7.4E-05	7.2E-05	1.8E-04		19/□		πeVs
Output longitudinal rms emittance		7.6E-07	1.0E-06	1.2E-06	1.4E-06	1.7E-06	2.3E-06		2/□		πeVs
Controlled beam loss; expected	0.05[a]	N/A	0.2[b]	N/A	N/A	N/A	N/A	5[c]	62[d]	58[e]	kW
Uncontrolled beam loss; expected	70	100[f]	2	1	1	0.2	0.2	<1	1	<1	W/m
Output H emittance (norm., rms)	0.2	0.21	0.27	0.33	0.39	0.41	0.41	0.46	44	44	πmm mr
Output V emittance (norm., rms)	0.2	0.21	0.27	0.33	0.39	0.41	0.41	0.46	44	44	πmm mr

Note a) corresponding to 27% chopped beam
b) corresponding to 5% chopped beam
c) beam loss on the transverse and momentum collimators
d) including total 4% of beam escaping foil and 0.2% beam loss on collimators
e) including 4% beam scattered on the target window
f) corresponding to 20% beam loss averaged over RFQ length
g) full acceptance without collimation

Beam Line Allocation

BL	Position*	Moderator	Instrument
1a	TU	Hydrogen decoupled	
1b	TU	Hydrogen decoupled	Disordered Materials Diffractometer (NOMAD)
2	TU	Hydrogen decoupled	High Resolution Backscattering Spectrometer
3	TU	Hydrogen decoupled	High Pressure Diffractometer (SNAP)
4a	TD	Hydrogen coupled	Magnetism Reflectometer
4b	TD	Hydrogen coupled	Liquids Reflectometer
5	TD	Hydrogen coupled	Cold Neutron Chopper Spectrometer (CNCS)
6	TD	Hydrogen coupled	Extended Range Small Angle Diffractometer
7	BU	Water	Engineering Diffractometer (Vulcan)
8a	BU	Water	
8b	BU	Water	
9	BU	Water	
10	TU	Hydrogen decoupled	
11a	TU	Hydrogen decoupled	Powder Diffractometer
11b	TU	Hydrogen decoupled	Macromolecular Diffractometer (MaNDi)
12	TU	Hydrogen decoupled	Single Crystal Diffractometer (SCD)
13	BD	Hydrogen coupled	Fundamental Physics
14a	BD	Hydrogen coupled	
14b	BD	Hydrogen coupled	Hybrid Spectrometer (HYSPEC)
15	BD	Hydrogen coupled	Neutron Spin Echo
16a	BU	Water	
16b	BU	Water	Vibrational Spectrometer (VISION)
17	BU	Water	High Resolution Chopper Spectrometer (Sequoia)
18		Water	Wide Angular Range Chopper Spectrometer (ARC

* T = Top, B = Bottom, U = Upstream, D = Downstream

WBS			Parameter	Base Value	Unit	Comment
1.	0.		**SPALLATION NEUTRON SOURCE**			
1.	0.		Proton beam power on target	1.4	MW	
1.	0.		Proton beam kinetic energy on target	1.0	GeV	
1.	0.		Average beam current on target	1.4	mA	
1.	0.		Pulse repetition rate	60	Hz	
1.	0.		Protons per pulse on target	$1.5x10^{14}$	protons	
1.	0.		Charge per pulse on target	24	μC	
1.	0.		Energy per pulse on target	24	kJ	
1.	0.		Proton pulse length on target	695	ns	
1.	0.		Ion type (Front end, Linac, HEBT)	H minus		
1.	0.		Average linac macropulse H- current	26	mA	from RFQ to injection foil
1.	0.		Linac beam macropulse duty factor	6	%	
1.	0.		Front end length	7.5	m	
1.	0.		Linac length	331	m	including 71 m for 9 empty cryomudule slots
1.	0.		HEBT length	170	m	
1.	0.		Accumulator ring circumference	248	m	
1.	0.		RTBT length	150	m	
1.	0.		Ion type (Ring, RTBT, Target)	proton		
1.	0.		Ring filling time	1.0	ms	
1.	0.		Ring revolution frequency	1.058	MHz	
1.	0.		Number of injected turns	1060		
1.	0.		Ring filling fraction	68	%	
1.	0.		Ring extraction beam gap	250	ns	
1.	0.		Maximum uncontrolled beam loss	1	W/m	
1.	0.		Target material	Hg		
1.	0.		Number of ambient / cold moderators	1/3		
1.	0.		Number of neutron beam shutters	18		
1.	0.		Initial number of instruments	5		
1.	3.		**FRONT END**			
1.	3.		Ion type	H minus		
1.	3.		Output energy	2.5	MeV	RFQ output
1.	3.		Length	7.52	m	From IS outlet flange to DTL
1.	3.		Beam-floor distance	1.270	m	50.0 in
1.	3.		Output peak current	38	mA	
1.	3.	1.	**ION SOURCE AND LEBT**			
1.	3.	1.	Output energy	65	keV	
1.	3.	1.	LEBT length	0.12	m	
1.	3.	1.	Output peak current	48	mA	Assuming 80% front end transmission
1.	3.	1.	Ion source type	RF volume production		Multicusp Cs-enhanced
1.	3.	1.	Electron suppression	magnetic		Interception at low energy
1.	3.	1.	LEBT focusing type	electrostatic		
1.	3.	1.	Estimated output rms norm H & V emittance	0.20	πmm-mrad	
1.	3.	1.	Ion source lifetime	3	weeks	Maintenance cycle
1.	3.	1.	Ion source replacement time	2	hours	With conditioned replacement ion source
1.	3.	1.	LEBT chopper rise time	45	ns	

WBS			Parameter	Base Value	Unit	Comment
1.	3.	1.	Ion source/ LEBT vacuum	1.e-4	Torr	
1.	3.	2.	**RFQ ACCELERATOR**			
1.	3.	2.	Output energy	2.5	MeV	
1.	3.	2.	Length	3.76	m	4 modules, incl. LEBT diagnostic plate
1.	3.	2.	Output peak current	38	mA	
1.	3.	2.	RF frequency	402.5	MHz	
1.	3.	2.	Nominal aperture radius	3.5	mm	
1.	3.	2.	Rms surface field during macropulse	1.85	Kilpatrick	
1.	3.	2.	Rms macropulse structure power	630	kW	Assumes 67% of Cu Q
1.	3.	2.	Expected output rms norm H & V emittance	0.21	πmm-mrad	
1.	3.	2.	Expected output rms L emittance	0.10	πMeV-deg	At 402.5 MHz
1.	3.	2.	Vacuum	1.e-6	Torr	
1.	3.		**RFQ RF SYSTEM**			
1.	3.		RF frequency	402.5	MHz	
1.	3.		Klystron peak power	2.5	MW	
1.	3.		Number of klystrons	1		
1.	3.		Modulator type	IGBT		
1.	3.		Number of klystrons per modulator	3		sharing with first 2 DTL klystrons
1.	3.		Klystron efficiency	58	%	
1.	3.		Static RF amplitude error	+/-1	%	
1.	3.		Static RF phase error	+/-1	degree	
1.	3.		Dynamic RF amplitude error	+/-0.5	%	
1.	3.		Dynamic RF phase error	+/-0.5	degree	
1.	3.	3.	**MEBT**			
1.	3.	3.	Output energy	2.5	MeV	
1.	3.	3.	Length	3.64	m	
1.	3.	3.	Output peak current	38	mA	
1.	3.	3.	Number of quadrupoles	14		
1.	3.	3.	Number of quadrupole PS	11		two symmetric triplets wired in series
1.	3.	3.	Quads 1-4 and 11-14 clear bore diameter	32	mm	
1.	3.	3.	Quads 5 - 10 clear bore diameter	42	mm	
1.	3.	3.	Maximum integrated quad gradient	2.4/1.9	T	Narrow/wide bore
1.	3.	3.	Number of two-plane beam steerers	6		Quad poletip windings
1.	3.	3.	Number of steerer PS	12		
1.	3.	3.	Number of rebuncher cavities	4		
1.	3.	3.	Rebuncher cavity frequency	402.5	MHz	
1.	3.	3.	Maximum rebuncher peak voltage integral	90	kV	
1.	3.	3.	Expected output rms norm H & V emittance with errors	0.27	πmm-mrad	
1.	3.	3.	Expected output rms L emittance with errors	0.13	πMeV-deg	At 402.5 MHz
1.	3.	3.	Expected max rebuncher cavity rms field error	2	%	
1.	3.	3.	Expected max rebuncher cavity rms phase error	1	deg	
1.	3.	3.	Expected max quad rms gradient error	<1	%	
1.	3.	3.	Expected max quad rms position error on sub-raft	0.025	mm	
1.	3.	3.	Expected max sub-raft rms position error on major support	0.04	mm	

WBS			Parameter	Base Value	Unit	Comment
1.	3.	3.	Expected max quad rms roll error	0.06	mrad	
1.	3.	3.	Expected max quad rms yaw error	0.06	mrad	
1.	3.	3.	Expected max quad rms pitch error	0.6	mrad	
1.	3.	3.	Vacuum	5.00E-07	Torr	
1.	3.		**MEBT RF SYSTEM**			
1.	3.		RF frequency	402.5	MHz	
1.	3.		RF power	20	kW	
1.	3.		RF amplitude rms error	2	%	
1.	3.		RF phase rms error	1	degree	
1.	**4.**	**5.**	**MEBT TRAVELING WAVE CHOPPERS**			
1.	4.	5.	Number of choppers	1		
1.	4.	5.	Chopper length	0.35	m	Each active structure
1.	4.	5.	Full rise/fall time	10	ns	
1.	4.	5.	Beam-on duty factor	68	%	
1.	4.	5.	Gap	18	mm	
1.	4.	5.	Total deflection voltage	+/- 2350	V	18 mrad deflection
1.	4.	5.	Post chopper off/on beam-current ratio	1.0E-4		
1.	3.	3.	**MEBT DIAGNOSTICS**			
1.	3.	3.	Number of beam current monitor	2		
1.	3.	3.	Number of beam profile monitors	5		Wire scanners
1.	3.	3.	Number of two-plane stripline BPMs	6		Inside quads, include phase measurement
1.	3.	3.	Number of emittance scanners	1		
1.	3.	3.	Number of neutron detectors	3		
1.	4.		**LINAC**			
1.	4.		Ion type	H minus		
1.	4.		Output energy	1.00	GeV	
1.	4.		Length	251.624	m	Excludes space for 9 more cryomodules
1.	4.		Beam-floor distance	1.270	m	50.0 in
1.	4.		Peak macropulse current	38	mA	
1.	4.		Average macropulse current	26	mA	For $P_{klystron}$ =550 kW
1.	4.		Average beam current	1.56	mA	
1.	4.		Average output beam power	1.56	MW	Expected value for linac
1.	4.		RF duty factor	7.2	%	HV gate duty factor
1.	4.		Expected output H & V rms norm emittance w/ errors and wo/ jitter	0.41	πmm-mrad	
1.	4.		Expected output transverse centroid jitter	+/- 0.25	mm	
1.	4.		Expected output H & V rms norm emittance w/ errors and w/ jitter	0.45	πmm-mrad	
1.	4.		Expected output L rms emittance w/ errors	0.6	πMeV-deg	At 805 MHz
1.	4.		Expected output rms energy spread	0.33	MeV	
1.	4.		Maximum output energy jitter	+/- 1.5	MeV	99.99%
1.	4.		Maximum phase centroid jitter	+/- 3.7	deg	At 805 MHz; 99.99%
1.	4.		Beam halo outside 5 sigma transverse	$< 1x10^{-4}$		
1.	4.		Beam residual inside chopper gap	$< 1x10^{-4}$		
1.	4.		Expected max quad gradient rms	0.14	%	Limit +/- 0.25 %

WBS			Parameter	Base Value	Unit	Comment
1.	4.		Expected max quad transverse displacement rms	0.07	mm	Limit +/- 0.13 mm
1.	4.		Expected max quad roll rms	3	mrad	Limit +/- 5 mrad
1.	4.		Expected max quad tilt rms	6	mrad	Limit +/- 10 mrad
1.	4.	2.	**DTL ACCELERATOR**			
1.	4.	2.	Output energy	86.8	MeV	
1.	4.	2.	Length	36.569	m	Tank 1 entry plane to tank 6 exit plane
1.	4.	2.	RF frequency	402.5	MHz	
1.	4.	2.	Average synchronous phase	-37 to -26		Phase ramped
1.	4.	2.	Number of tanks	6		
1.	4.	2.	Maximum field	1.3	Kilpatrick	At tank 1
1.	4.	2.	Bore radius	12.5	mm	
1.	4.	2.	Focusing structure	FFODDO		
1.	4.	2.	Focusing period	6	beta-lambda	
1.	4.	2.	Number of quads	147		
1.	4.	2.	Quadrupole type	permanent magnet		
1.	4.	2.	Integrated quad gradient	1.297	T	Average of measured values
1.	4.	2.	Quad location	inside DTs		
1.	4.	2.	Number of steering dipoles	24		All are individually powered
1.	4.	2.	Average operating vacuum pressure	1.8E-07	Torr	
1.	4.	2.	Tank 1 length	4.152	m	Between inside end walls
1.	4.	2.	Tank 1 number of cells	60		
1.	4.	2.	Tank 1 number of post couplers	19		
1.	4.	2.	Tank 1 energy gain	5.023	MeV	
1.	4.	2.	Tank 1 stored energy	4.78	J	
1.	4.	2.	Tank 1 Synchronous phase	-45 to -28	deg	
1.	4.	2.	Tank 1 average E_0T	1.518	MV/m	
1.	4.	2.	Tank 1 design shunt impedance ZT^2 (estimate)	28.22	MΩ/m	=<Superfish calc +stems+endwalls, no holes, tuners, couplers>/1.2
1.	4.	2.	Tank 1 design unloaded Q (estimate)	35,891		=<Superfish calc +stems+endwalls, no holes, tuners, couplers>/1.2
1.	4.	2.	Tank 1 design external Q (estimate)	23,554		=<Superfish calc +stems+endwalls, no holes, tuners, couplers>/1.2
1.	4.	2.	Tank 2 length	6.063	m	Between inside end walls
1.	4.	2.	Tank 2 number of cells	48		
1.	4.	2.	Tank 2 number of post couplers	23		
1.	4.	2.	Tank 2 energy gain	15.362	MeV	
1.	4.	2.	Tank 2 Synchronous phase	-25	deg	
1.	4.	2.	Tank 2 stored energy	16.51	J	
1.	4.	2.	Tank 2 average E_0T	2.810	MV/m	
1.	4.	2.	Tank 2 design shunt impedance ZT^2 (estimate)	45.25	MΩ/m	=<Superfish calc +stems+endwalls, no holes, tuners, couplers>/1.2
1.	4.	2.	Tank 2 design unloaded Q (estimate)	40,074		=<Superfish calc +stems+endwalls, no holes, tuners, couplers>/1.2
1.	4.	2.	Tank 2 design external Q (estimate)	26,480		=<Superfish calc +stems+endwalls, no holes, tuners, couplers>/1.2
1.	4.	2.	Tank 3 length	6.324	m	Between inside end walls
1.	4.	2.	Tank 3 number of cells	34		
1.	4.	2.	Tank 3 number of post couplers	16		

WBS			Parameter	Base Value	Unit	Comment
1.	4.	2.	Tank 3 energy gain	16.880	MeV	
1.	4.	2.	Tank 3 stored energy	21.84	J	
1.	4.	2.	Tank 3 Synchronous phase	-25	deg	
1.	4.	2.	Tank 3 average E_0T	2.966	MV/m	
1.	4.	2.	Tank 3 design shunt impedance ZT^2 (estimate)	43.54	MΩ/m	=<Superfish calc +stems+endwalls, no holes, tuners, couplers>/1.2
1.	4.	2.	Tank 3 design unloaded Q (estimate)	43,237		=<Superfish calc +stems+endwalls, no holes, tuners, couplers>/1.2
1.	4.	2.	Tank 3 design external Q (estimate)	29,468		=<Superfish calc +stems+endwalls, no holes, tuners, couplers>/1.2
1.	4.	2.	Tank 4 length	6.411	m	Between inside end walls
1.	4.	2.	Tank 4 number of cells	28		
1.	4.	2.	Tank 4 number of post couplers	27		
1.	4.	2.	Tank 4 energy gain	16.771	MeV	
1.	4.	2.	Tank 4 stored energy	22.22	J	
1.	4.	2.	Tank 4 Synchronous phase	-25	deg	
1.	4.	2.	Tank 4 average E_0T	2.907	MV/m	
1.	4.	2.	Tank 4 design shunt impedance ZT^2 (estimate)	41.91	MΩ/m	=<Superfish calc +stems+endwalls, no holes, tuners, couplers>/1.2
1.	4.	2.	Tank 4 design unloaded Q (estimate)	42,492		=<Superfish calc +stems+endwalls, no holes, tuners, couplers>/1.2
1.	4.	2.	Tank 4 design external Q (estimate)	29,812		=<Superfish calc +stems+endwalls, no holes, tuners, couplers>/1.2
1.	4.	2.	Tank 5 length	6.294	m	Between inside end walls
1.	4.	2.	Tank 5 number of cells	24		
1.	4.	2.	Tank 5 number of post couplers	23		
1.	4.	2.	Tank 5 energy gain	15.984	MeV	
1.	4.	2.	Tank 5 stored energy	22.05	J	
1.	4.	2.	Tank 5 Synchronous phase	-25	deg	
1.	4.	2.	Tank 5 average E_0T	2.886	MV/m	
1.	4.	2.	Tank 5 design shunt impedance ZT^2 (estimate)	40.83	MΩ/m	=<Superfish calc +stems+endwalls, no holes, tuners, couplers>/1.2
1.	4.	2.	Tank 5 design unloaded Q (estimate)	43,429		=<Superfish calc +stems+endwalls, no holes, tuners, couplers>/1.2
1.	4.	2.	Tank 5 design external Q (estimate)	29,981		=<Superfish calc +stems+endwalls, no holes, tuners, couplers>/1.2
1.	4.	2.	Tank 6 length	6.341	m	Between inside end walls
1.	4.	2.	Tank 6 number of cells	22		
1.	4.	2.	Tank 6 number of post couplers	21		
1.	4.	2.	Tank 6 energy gain	14.306	MeV	
1.	4.	2.	Tank 6 stored energy	21.47	J	
1.	4.	2.	Tank 6 Synchronous phase	-28 to -49	deg	
1.	4.	2.	Tank 6 average E_0T	2.777	MV/m	
1.	4.	2.	Tank 6 design shunt impedance ZT^2 (estimate)	39.03	MΩ/m	=<Superfish calc +stems+endwalls, no holes, tuners, couplers>/1.2
1.	4.	2.	Tank 6 design unloaded Q (estimate)	43,316		=<Superfish calc +stems+endwalls, no holes, tuners, couplers>/1.2
1.	4.	2.	Tank 6 design external Q (estimate)	30,863		=<Superfish calc +stems+endwalls, no holes, tuners, couplers>/1.2

WBS			Parameter	Base Value	Unit	Comment
1.	4.		**DTL RF SYSTEM**			
1.	4.		RF frequency	402.5	MHz	
1.	4.		Klystron peak power	2.5	MW	
1.	4.		Number of klystrons per tank	1		
1.	4.		Modulator type	IGBT		
1.	4.		Number of klystrons per modulator	2		first 2 tanks share with RFQ modulator
1.	4.		Klystron efficiency	58	%	
1.	4.		Static RF amplitude error	+/-1	%	
1.	4.		Static RF phase error	+/-1	degree	
1.	4.		Dynamic RF amplitude error	+/-0.5	%	
1.	4.		Dynamic RF phase error	+/-0.5	degree	
1.	4.	5.	**DTL DIAGNOSTICS**			
1.	4.	5.	Number of beam position and phase monitors	10		
1.	4.	5.	Number of beam loss monitors	12		
1.	4.	5.	Number of beam current monitors	6		
1.	4.	5.	Number of wire scanners	5		
1.	4.	5.	Number of Faraday cups	5		
1.	4.	5.	Number of neutron detectors	12		
1.	4.	4.	**CCL ACCELERATOR**			
1.	4.	4.	Output energy	185.6	MeV	
1.	4.	4.	Length	55.119	m	Not including space to CCL
1.	4.	4.	RF frequency	805	MHz	
1.	4.	4.	Number of accelerating cells per segment	8		
1.	4.	4.	Number of segments per module	12		
1.	4.	4.	Number of RF modules	4		
1.	4.	4.	DTL to CCL physics distance	0.248	m	Mechanical space 0.197 m
1.	4.	4.	Max field	1.3	Kilpatrick	
1.	4.	4.	Bore radius	15	mm	
1.	4.	4.	Focusing structure	FODO		
1.	4.	4.	Focusing period	13	beta-lambda	
1.	4.	4.	Number of quadrupoles	48		1 thin quad, 47 identical quads
1.	4.	4.	Quad type	EM		
1.	4.	4.	Quad integral gradient, entry-exit	2.51 - 0.77	T	
1.	4.	4.	Quad location	between segs.		Outside vacuum
1.	4.	4.	Number of quadrupole PS for matching	8		4 for DTL-CCL matching, 4 for CCL-SCL matching
1.	4.	4.	Number of primary quadrupole PS with shunts	5		each with 8 shunts powering 8 quadrupoles
1.	4.	4.	Number of special quadrupole PS	1		for thin quad
1.	4.	4.	Number of steering dipoles	32		
1.	4.	4.	Number of steerer PS	32		
1.	4.	4.	Average operating vacuum pressure	1.4 E-7	Torr	
1.	4.	4.	Module 1 length	11.839	m	Physics length
1.	4.	4.	Module 1 cell-to-cell coupling	5.3	%	
1.	4.	4.	Module 1 energy gain	20.334	MeV	
1.	4.	4.	Module 1 synchronous phase	-30	deg	
1.	4.	4.	Module 1 stored energy	6.63	J	
1.	4.	4.	Module 1 average E_0T	1.983	MV/m	Average over module length

WBS			Parameter	Base Value	Unit	Comment
1.	4.	4.	Module 1 design shunt impedance ZT^2 (estimate)	21.89	MΩ/m	Average over module length, =<Superfish calc +stems+endwalls, no holes, tuners, couplers>/1.2
1.	4.	4.	Module 1 design unloaded Q (estimate)	16,310		=<Superfish calc +stems+endwalls, no holes, tuners, couplers>/1.2
1.	4.	4.	Module 1 design external Q (estimate)	12,309		=<Superfish calc +stems+endwalls, no holes, tuners, couplers>/1.2
1.	4.	4.	Module 2 length	12.946	m	Physics length
1.	4.	4.	Module 2 cell-to-cell coupling	5.1	%	
1.	4.	4.	Module 2 energy gain	23.979	MeV	
1.	4.	4.	Module 2 synchronous phase	-30	deg	
1.	4.	4.	Module 2 stored energy	8.23	J	
1.	4.	4.	Module 2 average E_0T	2.139	MV/m	Average over module length
1.	4.	4.	Module 2 design shunt impedance ZT^2 (estimate)	24.02	MΩ/m	Average over module length, =<Superfish calc +stems+endwalls, no holes, tuners, couplers>/1.2
1.	4.	4.	Module 2 design unloaded Q (estimate)	17,418		=<Superfish calc +stems+endwalls, no holes, tuners, couplers>/1.2
1.	4.	4.	Module 2 design external Q (estimate)	13,089		=<Superfish calc +stems+endwalls, no holes, tuners, couplers>/1.2
1.	4.	4.	Module 3 length	14.001	m	Physics length
1.	4.	4.	Module 3 cell-to-cell coupling	4.8	%	
1.	4.	4.	Module 3 energy gain	26.074	MeV	
1.	4.	4.	Module 3 average synchronous phase	-29.5	deg	Phase ramped
1.	4.	4.	Module 3 stored energy	8.83	J	
1.	4.	4.	Module 3 average E_0T	2.14	MV/m	Average over module length
1.	4.	4.	Module 3 design shunt impedance ZT^2 (estimate)	25.71	MΩ/m	Average over module length, =<Superfish calc +stems+endwalls, no holes, tuners, couplers>/1.2
1.	4.	4.	Module 3 design unloaded Q (estimate)	18,432		=<Superfish calc +stems+endwalls, no holes, tuners, couplers>/1.2
1.	4.	4.	Module 3 design external Q (estimate)	13,597		=<Superfish calc +stems+endwalls, no holes, tuners, couplers>/1.2
1.	4.	4.	Module 4 length	14.995	m	Physics length
1.	4.	4.	Module 4 cell-to-cell coupling	4.56	%	
1.	4.	4.	Module 4 energy gain	28.412	MeV	
1.	4.	4.	Module 4 average synchronous phase	-28	deg	Phase ramped
1.	4.	4.	Module 4 stored energy	9.41	J	
1.	4.	4.	Module 4 average E_0T	2.143	MV/m	Average over module length
1.	4.	4.	Module 4 design shunt impedance ZT^2 (estimate)	27.29	MΩ/m	Average over module length, =<Superfish calc +stems+endwalls, no holes, tuners, couplers>/1.2
1.	4.	4.	Module 4 design unloaded Q (estimate)	19,311		=<Superfish calc +stems+endwalls, no holes, tuners, couplers>/1.2
1.	4.	4.	Module 4 design external Q (estimate)	13,975		=<Superfish calc +stems+endwalls, no holes, tuners, couplers>/1.2
1.	4.	4.	Rms tolerance for distance between end gaps of segs	0.15	mm	Limit +/- 0.25 mm
1.	4.	4.	Rms tolerance between adjacent gaps in a segment	0.03	mm	Limit +/- 0.05 mm

WBS			Parameter	Base Value	Unit	Comment
1.	4.	4.	Rms tolerance of seg. end transverse displacement	0.3	mm	Limit +/- 0.5 mm
1.	4.		**CCL RF SYSTEM**			
1.	4.		RF frequency	805	MHz	
1.	4.		Klystron peak power	5	MW	
1.	4.		Number of klystrons per module	1		
1.	4.		Modulator type	IGBT		
1.	4.		Number of klystrons per modulator	1		
1.	4.		Klystron efficiency	55	%	
1.	4.		Static RF amplitude error	+/-1	%	
1.	4.		Static RF phase error	+/-1	degree	
1.	4.		Dynamic RF amplitude error	+/-0.5	%	
1.	4.		Dynamic RF phase error	+/-0.5	degree	
1.	4.	5.	**CCL DIAGNOSTICS**			
1.	4.	5.	Number of beam position and phase monitors	10		
1.	4.	5.	Number of beam loss monitors	28		including one in DTL-CCL transition
1.	4.	5.	Number of current monitors	1		
1.	4.	5.	Number of wire scanners	7		
1.	4.	5.	Number of Faraday cups	1		
1.	4.	5.	Number of bunch shape monitors	3		
1.	4.	5.	Number of neutron detectors	8		
1.	4.		**SUPERCONDUCTING RF LINAC**			
1.	4.		Output energy	1.00	GeV	
1.	4.		Length	157.321	m	23 cryomodules + 22 warm spaces
1.	4.		RF frequency	805	MHz	
1.	4.		Transition energy between sections	387	MeV	Design value
1.	4.		Focusing structure	Doublet		warm quads between cryos outside vacuum
1.	4.		Number of quadrupoles	67		Includes doublet for CCL-SCL transition
1.	4.		Number of quadrupoles with H&V dipole windings	67		32 Powered
1.	4.		Quad type	EM		
1.	4.		Number of quadrupole PS for matching	8		2 for CCL-SCL matching, 6 for SCL-HEBT matching
1.	4.		Number of quadrupole PS for doublets	29		2 with shunts for SCL1 and SCL2 transition
1.	4.		Number of steerer PS	32		
1.	4.		Peak med beta cavity surface field	27.5	MV/ m	Uncertainty is +/- 2.5 MV/m
1.	4.		Peak high beta cavity surface field	35.0	MV/ m	Uncertainty is +2.5 / -7.5MV/m
1.	4.		Medium beta cavity geometrical beta	0.61		
1.	4.		High beta cavity geometrical beta	0.81		
1.	4.		Number of med beta cryomodules	11		
1.	4.		Number of high beta cryomodules	12		
1.	4.		Warm space between cryomodule valves	1.6	m	Between gate valves
1.	4.		Period length med beta	5.839	m	
1.	4.		Period length high beta	7.891	m	
1.	4.		Length of 186 MeV differential pumping section	2.35	m	CCL to SRF distance
1.	4.		Length for nine additional high beta cryomodules	71.019	m	

WBS		Parameter	Base Value	Unit	Comment
1.	4.	Warm beam pipe vacuum	1.E-09	Torr	
1.	4.	**SRF LINAC CAVITIES**			
1.	4.	Cavity type	elliptical		
1.	4.	Cavity operating mode	pi		
1.	4.	Cavity material	Niobium		
1.	4.	Cavity material thickness	4	mm	3.8 mm after processing
1.	4.	Cavity operating temperature	2.1	K	
1.	4.	Number of cells per cavity	6		
1.	4.	Cavities per cryomodule med beta	3		
1.	4.	Cavities per cryomodule high beta	4		
1.	4.	Med beta coupling constant	1.61	%	
1.	4.	High beta coupling constant	1.61	%	
1.	4.	Qo med beta	>5E+9		
1.	4.	Qo high beta	>5E+9		
1.	4.	r/Q med beta	220-440	Ω/m	Function of beam velocity, r/Q=Rsh/Qo
1.	4.	r/Q high beta	170-570	Ω/m	Function of beam velocity, r/Q=Rsh/Qo
1.	4.	Medium Beta Cavity external Q	7.30E+05		
1.	4.	High Beta Cavity external Q	7.00E+05		
1.	4.	External Q variation	+/- 20	%	
1.	4.	Half band width (-3 db point), med β, high β	550, 575	Hz	$f(1/2)=f_0/(2Q_{ex})$
1.	4.	Cavity stiffeners	yes		
1.	4.	Piezo tuners	81		1 per medium and high beta cavitiy
1.	4.	Expected frequency swing due to Lorentz force with piezo compensation	< 470	Hz	
1.	4.	Microphonic amplitude limit	+/- 100	Hz	Six sigma
1.	4.	Maximum detuning range, med. Beta	2300	Hz	Most heavily loaded cavity - no piezo compensation, klystron power limit
1.	4.	Maximum detuning range, high Beta	1000	Hz	Most heavily loaded cavity - no piezo compensation, klystron power limit
1.	4.	Available Klystron power, med. Beta	408	kW	
1.	4.	Available Klystron power, high Beta	522	kW	
1.	4.	Cavity active length med beta	0.682	m	
1.	4.	Cavity active length high beta	0.906	m	
1.	4.	Total cavity length med beta	1.067	m	
1.	4.	Total cavity length high beta	1.291	m	
1.	4.	E_{peak}/E_0 med beta	1.84		
1.	4.	E_{peak}/E_0 high beta	1.53		
1.	4.	B_{peak}/E_{peak} med beta	2.10	mT//MV/m	
1.	4.	B_{peak}/E_{peak} high beta	2.14	mT//MV/m	
1.	4.	E_0 med beta	13.4 - 16.4	MV/m	Not including the Transit Time Factor (~ 0.70 for matched beta cavity)
1.	4.	E_0 high beta	17.9 - 24.4	MV/m	Not including the Transit Time Factor (~ 0.72 for matched beta cavity)
1.	4.	Energy gain per cavity, med. Beta	4.61 - 6.77	MeV	
1.	4.	Energy gain per cavity, high Beta	8.17 - 14.41	MeV	
1.	4.	B_{peak} med beta	52.0 - 63.5	mT	
1.	4.	B_{peak} high beta	58.9 - 80.3	mT	

WBS			Parameter	Base Value	Unit	Comment
1.	4.		Cavity field flattness	8	%	$(V_{max} - V_{min})/ V_{avg}$, after welding
1.	4.		Synchronous phase med beta	20.5	deg	
1.	4.		Synchronous phase high beta	19.5	deg	
1.	4.		**SRF LINAC CRYOMODULES**			
1.	4.		Shield static heat load med beta cryomodule	170	W	
1.	4.		Shield static heat load high beta cryomodule	200	W	
1.	4.		2.1 K static heat load med beta cryomodule	25	W	
1.	4.		2.1 K static heat load high beta cryomodule	28	W	
1.	4.		Cavity dynamic heat load per med beta cryomodule	16	W	
1.	4.		Cavity dynamic heat load per high beta cryomodule	28	W	
1.	4.		Magnetic field at cryomodules from rebar	0.0001	T	
1.	4.		Cavity displacement tolerance relative to cryomodule	+/-1	mm	Maximum
1.	4.		Cavity tilt tolerance relative to cryomodule	+/-1	mrad	Maximum
1.	4.		Cryomodule transverse alignment tolerance	+/-1	mm	Maximum
1.	4.		**SRF LINAC POWER COUPLERS**			
1.	4.		Power couplers per cavity	1		
1.	4.		Number of power couplers	81		
1.	4.		Maximum power of coupler	550	kW	
1.	4.		Power coupler type	KEK-B		
1.	4.		Power coupler vacuum	5.E-09	Torr	
1.	4.		**SRF LINAC HOM COUPLERS**			
1.	4.		HOM couplers per cavity	2		
1.	4.		Number of HOM couplers	2 x 81		
1.	4.		HOM coupler type	TTF		
1.	4.		Qext at 805 MHz	$> 3x10^{10}$		medium beta
1.	4.		Qext at 805 MHz	$> 7.5x10^{10}$		high beta
1.	4.		**SRF LINAC TUNERS**			
1.	4.		Number of tuners	81		
1.	4.		Tuner tuning rate	3000	Hz/sec	Minimum
1.	4.		Tuner tuning range	+/-100	kHz	from 805 MHz
1.	4.		**SRF LINAC RF SYSTEM**			
1.	4.		RF frequency	805	MHz	
1.	4.		Klystron peak power	0.55	MW	
1.	4.		Number of klystrons per cavity	1		
1.	4.		Modulator type	IGBT		
1.	4.		Number of klystrons per modulator	12, 11		total of 7 modulators
1.	4.		Klystron efficiency	68	%	
1.	4.		Dynamic RF amplitude error	+/-0.5	%	
1.	4.		Dynamic RF phase error	+/-0.5	degree	
1.	4.	12.	**SRF LINAC CRYOPLANT**			
1.	4.	12.	Primary circuit temperature	2.1	K	
1.	4.	12.	Primary circuit pressure	0.041	bar	

WBS			Parameter	Base Value	Unit	Comment
1.	4.	12.	Primary circuit heat removal capacity	2.4	kW	at 2.1 K
1.	4.	12.	Primary circuit margin	100	%	50 % @ 1.3GeV
1.	4.	12.	Secondary circuit temperature	5	K	
1.	4.	12.	Secondary circuit pressure	3	bar	
1.	4.	12.	Secondary circuit margin	100	%	
1.	4.	12.	Shield circuit temperature	35-55	K	
1.	4.	12.	Shield circuit pressure	4.0-3.0	bar	
1.	4.	12.	Shield circuit margin	50	%	
1.	4.	9.	**SRF LINAC FOCUSING QUADRUPOLES**			
1.	4.	9.	Aperture diameter	80	mm	
1.	4.	9.	Effective length	0.39	m	
1.	4.	9.	Max gradient	7.2	T/m	
1.	4.	5.	**SRF LINAC DIAGNOSTICS**			not including linac dump line
1.	4.	5.	Number of beam position and phase monitors	34		2 in CCL-SCL transition
1.	4.	5.	Number of beam loss monitors	86		1 in CCL-SCL transition (PCR pending)
1.	4.	5.	Number of current monitors	1		1 in CCL-SCL transition
1.	4.	5.	Number of wire scanners	9		1 in CCL-SCL transition + 8 laser wire monitors pending
1.	4.	5.	Number of neutron detectors	7		
1.	5.	1.	**HEBT BEAM LINE**			
1.	5.	1.	Ion type	H minus		
1.	5.	1.	Output energy	1.00	GeV	
1.	5.	1.	Length	169.49	m	Diff pumping to injection septum center
1.	5.	1.	Beam-floor distance	1.270	m	50.0 in
1.	5.	1.	Length of additional linac dump beam line	42	m	
1.	5.	1.	Length of linac to achromat matching section LAMS	40	m	
1.	5.	1.	Number of LAMS FODO cells	5		8.0 m per FODO cell
1.	5.	1.	Length of achromat	59	m	
1.	5.	1.	Number of achromat FODO cells	4		14.0 m per FODO cell
1.	5.	1.	Achromat total bend angle	90	deg	
1.	5.	1.	Achromat maximum dispersion	6.8	m	
1.	5.	1.	Length of achromat to ring matching section ARMS	70	m	
1.	5.	1.	Number of ARMS FODO cells	7.5		8.0 m per FODO cell
1.	5.	1.	Number of Ludewig betatron collimators	2		
1.	5.	1.	Number of betatron foil scrapers	4		4 pairs
1.	5.	1.	Location of momentum scraper	achromat center		1 pair
1.	5.	1.	Maximum power on each Ludwig collimator	2	kW	
1.	5.	1.	Rms energy spread at achromat center	0.72	MeV	
1.	5.	1.	Energy scrape with momentum collimator	+/- 3.0	MeV	
1.	5.	1.	Energy total jitter before energy corrector	+/- 1.5	MeV	
1.	5.	1.	Energy total jitter after energy corrector	+/- 0.2	MeV	
1.	5.	1.	Total time ave energy spread at foil	+/- 4.0	MeV	
1.	5.	1.	Number of energy sweeps per macropulse	100		

WBS			Parameter	Base Value	Unit	Comment
1.	5.	1.	Expected output H&V rms norm emittance w/ errors and wo/ jitter	0.46	πmm-mrad	
1.	5.	1.	Extected output transverse centroid jitter	+/- 0.2	mm	
1.	5.	1.	Expected output H&V rms norm emittance w/ errors and w/ jitter	0.50	πmm-mrad	
1.	5.	1.	Operating vacuum pressure	5E-8 to 1E-8	Torr	From SRFL to Ring
1.	5.	1.	**HEBT MAGNETS**			
1.	5.	1.	Number of 11.25 deg C type dipoles	8		
1.	5.	1.	11.25 deg dipole field	0.20	T	
1.	5.	1.	11.25 deg dipole gap	80	mm	
1.	5.	1.	11.25 deg dipole length	5.43	m	Effective length
1.	5.	1.	Number of 8.75486 deg dipoles	1		
1.	5.	1.	8.75486 deg dipole field	0.21	T	
1.	5.	1.	8.75486 deg dipole gap	80	mm	
1.	5.	1.	8.75486 deg dipole length	4.134	m	
1.	5.	1.	Number of 12 cm bore quadrupoles	32		26 (HEBT) + 6 (linac dump)
1.	5.	1.	12 cm bore quad gradient	5.5	T/m	
1.	5.	1.	12 cm bore quad length	0.505	m	
1.	5.	1.	Number of 21 cm bore quadrupoles	8		Same as ring quads
1.	5.	1.	21 cm bore quad gradient	3	T/m	
1.	5.	1.	21 cm bore quad length	0.504	m	Effective length
1.	5.	1.	Number of 26.4 cm bore injection dump quadruples	1		
1.	5.	1.	Number of 12x12 cm dipole correctors	14		
1.	5.	1.	Number of 24x24 cm correctors	4		
1.	5.	1.	Expected dipole magnetic field errors	+/- 0.1	%	Integrated at full acceptance
1.	5.	1.	Expected quadrupole magnetic field errors	+/- 0.1	%	Integrated at full acceptance
1.	5.	1.	Expected corrector magnetic field errors	+/- 1	%	Integrated at full acceptance
1.	5.	1.	Expected magnet offset rms	0.1	mm	
1.	5.	1.	Magnet pitch and yaw rms tolerance	1	mrad	
1.	5.	1.	Magnet roll rms tolerance	1	mrad	
1.	5.	1.	Number of dipole PS	3		700 A and 40,40,150 V
1.	5.	1.	Number of quadrupole PS	26		200-800 A and 15-60 V
1.	5.	1.	Number of corrector bipolar PS	18		20 A and 30 V
1.	4.	5.	**HEBT RF CAVITIES**			
1.	4.	5.	Number energy corrector cavity	1		
1.	4.	5.	Energy corrector cavity location	115	m	From the last cavity of linac
1.	4.	5.	Energy corrector frequency	805	MHz	Same as CCL
1.	4.	5.	Energy corrector phase slip	18	deg/MeV	
1.	4.	5.	Energy corrector operation voltage	3.2	MV	
1.	4.	5.	Energy corrector aperture diameter	50	mm	
1.	4.	5.	Energy corrector peak voltage gain EoTL	4	MV	
1.	4.	5.	Number energy spreader cavity	1		
1.	4.	5.	Energy spreader cavity location	174	m	From the last cavity of linac
1.	4.	5.	Energy spreader frequency	805.0 +/- 0.1	MHz	Same as CCL
1.	4.	5.	Energy spreader aperture diameter	50	mm	
1.	4.	5.	Energy spreader peak voltage gain EoTL	4	MV	
1.	4.	5.	Number of cells per cavity	6		

WBS			Parameter	Base Value	Unit	Comment
1.	4.		**HEBT RF SYSTEM**			
1.	4.		RF frequency	805	MHz	
1.	4.		Klystron peak power	5	MW	
1.	4.		Number of klystrons per cavity	1		
1.	4.		Modulator type	IGBT		
1.	4.		Number of klystrons per modulator	2		
1.	4.		Klystron efficiency	55	%	
1.	4.		Static RF amplitude error	+/-1	%	
1.	4.		Static RF phase error	+/-1	degree	
1.	4.		Dynamic RF amplitude error	+/-0.5	%	
1.	4.		Dynamic RF phase error	+/-0.5	degree	
1.	5.	7.	**HEBT DIAGNOSTICS**			
1.	5.	7.	Number of beam position and phase monitors	37		includes 6 in linac dump + 1 in Inj dump
1.	5.	7.	Number of beam loss monitors	62		Includes both fast and slow monitors, and 6 linac dump + 7 injection dump
1.	5.	7.	Number of current monitors	5		Includes one for injection dump
1.	5.	7.	Number of profile measurments	13		Includes 1 in linac dump + 1 in inject. dump
1.	5.		**ACCUMULATOR RING**			
1.	5.		Ion type	proton		
1.	5.		Output energy	1.00	GeV	
1.	5.		Ring circumference	248.0	m	
1.	5.		Beam-floor distance	1.224	m	48.189 inch
1.	5.		Average beam power	1.5	MW	Average power in ring
1.	5.		Peak bunched beam current	52	A	
1.	5.		Proton magnetic rigidity	5.6575	Tm	
1.	5.		Max uncontrolled beam loss	1	W/m	
1.	5.		Unnormalized 99% total emittance (ε_x+ε_y)	240	πmm-mrad	434 πmm-mrad normalized; under study
1.	5.		Ring betatron acceptance	480	πmm-mrad	
1.	5.		Adjustable scraper acceptance	160-300	πmm-mrad	
1.	5.		Collimator acceptance	300	πmm-mrad	
1.	5.		Longitudinal rf bucket area	19	eV-sec	
1.	5.		Expected longitudinal bunch area (99%)	13	eV-sec	
1.	5.		Total Injected energy spread	+/- 4	MeV	
1.	5.		Total extracted energy spread	+/- 10	MeV	
1.	5.		RF system momentum acceptance	+/- 1.0	%	
1.	5.		Vacuum chamber full-beam momentum acceptance	+/- 2.0	%	
1.	5.		Zero betatron amplitude momentum acceptance	+/- 3.8	%	
1.	5.		Bunching factor	0.48		Dual harmonic RF
1.	5.		Expected space charge tune shift	0.15		Uniform-beam tune shift 0.1
1.	5.		Lattice superperiods	4		
1.	5.		Max dispersion in straight sections	<0.3	m	Dominated by injection chicane/bump
1.	5.		Arc lattice	4 FODO cells		
1.	5.		Arc FODO cell length	8	m	

WBS			Parameter	Base Value	Unit	Comment
1.	5.		Straight section lattice	2 doublets		
1.	5.		Short drift in long straights	2X6.85	m	
1.	5.		Long drift in long straights	12.5	m	
1.	5.		Phase advance per arc FODO cell	90	deg	
1.	5.		Nominal betatron H tune	6.23		Adjustable range 6 - 7
1.	5.		Nominal betatron V tune	6.20		Adjustable range 4 - 7
1.	5.		Transition gamma	5.23		
1.	5.		Frequency slip factor	-0.198		
1.	5.		Natural H chromaticity	-7.9		Nominal tunes
1.	5.		Natural V chromaticity	-6.9		Nominal tunes
1.	5.		Maximum dispersion function	4.0	m	Nominal tunes
1.	5.		Maximum H/V β function	27.9/15.7	m	Nominal tunes
1.	5.		Ring V beamline offset wrt HEBT beamline	-46	mm	
1.	5.		Chicane amplitude	100	mm	
1.	5.		Offset for injection H static bump	100	mm	
1.	5.		Number of injected turns	1060	turns	
1.	5.		Revolution period	945	ns	
1.	5.		Ring injection pulse length	645	ns	
1.	5.		Ring injection gap length	300	ns	
1.	5.		Ring extraction pulse length	695	ns	
1.	5.		Ring extraction gap length	250	ns	
1.	5.		Space charge longitudinal impedance Z/n	-196j	Ω	
1.	5.		Expected resistive wall longitudinal impedance Z/n	(1+j)0.7	Ω	At revolution frequency
1.	5.		Expected resistive wall transverse impedance Z	(1+j)8.5	kΩm	At revolution frequency
1.	5.		Expected broad band longitudinal impedance Z/n	9j	Ω	Below 10 MHz
1.	5.		Expected broad band transverse impedance Z/~~n~~	60j	kΩm	Below 10 MHz
1.	5.		Expected extraction kicker longitudinal impedance total |Z/n|	0.6n+50j	Ω	
1.	5.		Expected extraction kicker transverse impedance total, Z	33+125j	kΩm	Below 10 MHz
1.	5.		Expected extraction kicker transverse impedance total, Z	12.5+65j	kΩm	Near 50 MHz
1.	5.	2.	**RING INJECTION SYSTEM**			
1.	5.	2.	Foil half size HxV	5.1x5.5	mm	3 open sides
1.	5.	2.	Foil thickness	300	μg/cm^2	
1.	5.	2.	Linac beam missing foil	< 4	%	
1.	5.	2.	Stripped electron beam dump	carbon composite		Mounted on water cooled Cu block
1.	5.	2.	Transverse painting scheme	correlated		
1.	5.	2.	Average foil hits per proton	5		
1.	5.	2.	Number of dc horizontal chicane dipoles	4		
1.	5.	2.	Number of injection dc PS (4 dipole, 2 septum, 1 quad)	7		820-4000 A and ~20 V
1.	5.	2.	Horizontal dynamic bump amplitude	40	mm	
1.	5.	2.	Vertical dynamic bump amplitude	46	mm	
1.	5.	2.	Number of H and V injection kicker magnets	4 and 4		
1.	5.	2.	Number of injection kicker PS	8		1400A-800V
1.	5.	2.	Programmable injection kicker PS	yes		
1.	5.	2.	Expected chicane dipole magnetic field errors	+/- 0.1	%	Integrated at full acceptance

WBS			Parameter	Base Value	Unit	Comment
1.	5.	2.	Expected injection kicker field errors	+/- 1.0	%	Integrated at full acceptance
1.	5.	3.	**RING MAGNET SYSTEM**			
1.	5.	3.	Core material	1006 steel		Solid core
1.	5.	3.	Number of H frame sector dipoles	32		33 w/ reference dipole
1.	5.	3.	Dipole magnetic field	0.7935	T	
1.	5.	3.	Dipole bend angle	11.25	deg	Bending radius = 7.996 m
1.	5.	3.	Dipole gap	170	mm	HGFW = 230 mm
1.	5.	3.	Dipole pole width	450	mm	
1.	5.	3.	Dipole magnetic path length	1.4407	m	
1.	5.	3.	Dipole radius of curvature	7.3374	m	
1.	5.	3.	Dipole sagitta	35.332	mm	
1.	5.	3.	Number of arc regular quadrupoles	28		
1.	5.	3.	Bore of arc regular quads	210	mm	
1.	5.	3.	Magnetic length of arc regular quads	0.50	m	
1.	5.	3.	Magnetic gradient of arc regular quads	4.7	T/m	
1.	5.	3.	Number of arc large quadrupoles	8		
1.	5.	3.	Bore of arc large quads	264	mm	
1.	5.	3.	Magnetic length of arc large quads	0.50	m	
1.	5.	3.	Magnetic gradient of arc large quads	4.7	T/m	
1.	5.	3.	Number of straight section long quadrupoles	8		
1.	5.	3.	Bore of straight section long quads	300	mm	
1.	5.	3.	Magnetic length of straight section long quads	0.70	m	
1.	5.	3.	Magnetic gradient of straight section long quads	4.3	T/m	
1.	5.	3.	Number of straight section short quadrupoles	8		
1.	5.	3.	Bore of straight section short quads	300	mm	
1.	5.	3.	Magnetic length of straight section short quads	0.55	m	
1.	5.	3.	Magnetic gradient of straight section short quads	4.3	T/m	
1.	5.	3.	Number of 27x27 cm dipole and multipole correctors	28		
1.	5.	3.	Number of 36x36 cm dipole correctors	8		
1.	5.	3.	Number of 41x41 cm dipole correctors	8		
1.	5.	3.	Number of 21x21 cm sextupole & octupole correctors	8+8		
1.	5.	3.	Expected ring dipole magnetic field errors	+/- 0.01	%	Integrated at full acceptance
1.	5.	3.	Expected ring quadrupole magnetic field errors	+/- 0.01	%	Integrated at full acceptance
1.	5.	3.	Expected chromatic sextupoles field error	+/- 1.0	%	Integrated at full acceptance
1.	5.	3.	Expected corrector magnetic field errors	+/- 1.0	%	Integrated at full acceptance
1.	5.	3.	Expected magnet rms offset	0.1	mm	
1.	5.	3.	Expected magnet rms roll	0.2	mrad	
1.	5.	3.	Magnet pitch & yaw rms alignment tolerance	0.5	mrad	
1.	5.	3.	Magnet twist rms tolerance	0.5	mrad	
1.	5.	4.	**RING POWER SUPPLIES**			
1.	5.	4.	Number of dipole primary PS	1		4600 A, 400 V
1.	5.	4.	Number of quad primary PS	6		900-1000 A; 300-500 V
1.	5.	4.	Number of sextupole primary PS	4		
1.	5.	4.	Number of dipole corrector PS	54		20 A and 35 V, includes 2 in injection dump line
1.	5.	4.	Number of quadrupole trim PS	16		

WBS			Parameter	Base Value	Unit	Comment
1.	5.	4.	Number of sextupole corrector PS	8		
1.	5.	4.	Number of skew quadrupole corrector PS	28		
1.	5.	4.	Number of skew sextupole corrector PS	8		
1.	5.	4.	Number of octupole corrector PS	8		
1.	5.	5.	**RING VACUUM SYSTEM**			
1.	5.	5.	Average operating vacuum pressure	1.0E-08	Torr	
1.	5.	5.	Chamber material	Stainless steel		
1.	5.	5.	Coating material	TiN		
1.	5.	5.	Coating thickness	100	nm	
1.	5.	6.	**RING RF SYSTEM**			
1.	5.	6.	RF system type	dual harm		
1.	5.	6.	Cavity length	1.7	m	
1.	5.	6.	Accelerating gaps per cavity	2		
1.	5.	6.	Harmonic 1 frequency	1.058	MHz	
1.	5.	6.	Number of harmonic 1 cavities	3		
1.	5.	6.	Harmonic 1 total voltage	40	kV	
1.	5.	6.	Harmonic 2 frequency	2.115	MHz	
1.	5.	6.	Number of harmonic 2 cavities	1		
1.	5.	6.	Harmonic 2 total voltage	20	kV	
1.	5.	6.	Beam loading compensation	dynamic tuning & feed forward		
1.	5.	6.	Low level loop bandwidth	16	kHz	
1.	5.	6.	Harmonic 1 cavity shunt impedance	5000	Ω	loaded, with dynamic tuning
1.	5.	6.	Harmonic 1 cavity quality factor	15		loaded
1.	5.	6.	Harmonic 1 cavity peak RF power	100	kW/PA	with dynamic tuning
1.	5.	6.	Harmonic 1 cavity beam loading parameter	4.5		at design intensity with dynamic tuning
1.	5.	6.	Harmonic 2 cavity shunt impedance	2700	Ω	loaded, with dynamic tuning
1.	5.	6.	Harmonic 2 cavity quality factor	15		loaded
1.	5.	6.	Harmonic 2 cavity peak RF power	100	kW/PA	with dynamic tuning
1.	5.	6.	Harmonic 2 cavity beam loading parameter	1.2		at design intensity with dynamic tuning
1.	5.	7.	**RING DIAGNOSTICS**			
1.	5.	7.	Number of beam position monitors	44		Striplines at each quad
1.	5.	7.	Number of beam loss monitors	82		Fast and slow monitors
1.	5.	7.	Number of beam current monitors	1		
1.	5.	7.	Number of wall current monitors	1		
1.	5.	7.	Number of wire scanners	2		
1.	5.	7.	Number of foil video monitors	3		Primary and secondary stripping locations + e catcher
1.	5.	7.	Number of beam in gap monitors/cleaners	1		Kicker with PMT detectors
1.	5.	7.	Number of kicker elements	3		1.5 m long each
1.	5.	7.	Kicker strength	7	kV	0.2 mrad/kicker element
1.	5.	7.	Kicker rise time	20	nsec	
1.	5.	7.	Number of ionization profile monitors	2		Residual gas ionization monitor 1 ea H and V
1.	5.	7.	Number of tune measurement systems	3		1. BIG Kicker excited and FFT analyzed 2. Low power high frequency 3. Quadrupole pickup/monitor

WBS			Parameter	Base Value	Unit	Comment
1.	5.	7.	Number of electron detectors	5		Argonne style
1.	5.	7.	Scrapers	2		
1.	5.	8.	**RING COLLIMATION**			
1.	5.	8.	Number of independent adjustable scrapers	4		
1.	5.	8.	Scraper material	Ta		
1.	5.	8.	Number of Ludewig type collimators	3		
1.	5.	8.	Collimation efficiency	90	%	For 480 πmm mrad acceptance
1.	5.	8.	Power absorption capacity per collimator	2	kW	
1.	5.	9.	**RING EXTRACTION**			
1.	5.	9.	Extraction type	single turn		Fast kicker and Lambertson
1.	5.	9.	Beam extraction time gap	250	ns	
1.	5.	9.	Kicker rise time	200	ns	0 to 97%
1.	5.	9.	Kicker flattop time	700	ns	
1.	5.	9.	Number of fast ferrite kicker sections	14		
1.	5.	9.	Kicker core length per section	3x350 4x455 4x375 3x340	mm	Core spacing 130 mm
1.	5.	9.	Vertical displacement at Lambertson entrance	169	mm	
1.	5.	9.	Beam extracts to target with 13 of 14 kickers inoperable	yes		
1.	5.	9.	Number of PFNs	14		
1.	5.	9.	Number of PFN PS	14		
1.	5.	9.	Lambertson horizontal bend angle	16.8	deg	
1.	5.	9.	Lambertson rotation angle	2.55	deg	
1.	5.	9.	Lambertson core length	2.47	m	
1.	5.	9.	Lambertson magnetic field	0.628966	T	for 1GeV
1.	5.	9.	Expected extraction Lambertson magnetic field errors +/-	0.1	%	Integrated at full acceptance
1.	5.	9.	Expected extraction kicker field errors +/-	1.0	%	Integrated at full acceptance
1.	5.	9.	Number of Lambertson PS	1		2000 A, 20V
1.	5.	10.	**RTBT BEAM LINE**			
1.	5.	10.	Ion type	proton		
1.	5.	10.	Output energy	1.00	GeV	
1.	5.	10.	Length	150.75	m	Lambertson center to target
1.	5.	10.	Beam-floor distance	0.996 to 1.0414	m	Start at 39.2 in and end at 41.0 in
1.	5.	10.	Output beam power	1.5	MW	Average power
1.	5.	10.	Beam spot size on target H x V	200 x 70	mm	
1.	5.	10.	Number of Ludewig betatron collimators	2		
1.	5.	10.	Number of 11.6 m FODO cells	15		
1.	5.	10.	Ring extraction dump beam line length	28	m	
1.	5.	10.	RTBT elevation wrt ring	-0.1826	m	
1.	5.	10.	Operating vacuum pressure	1E-8 to 1E-7	Torr	From ring to target
1.	5.	10.	**RTBT MAGNETS**			
1.	5.	10.	Number of 16.8 deg H switcher dipole	1		
1.	5.	10.	Switching dipole gap	170	mm	
1.	5.	10.	Number of 21 cm bore quads	23		
1.	5.	10.	Number of 31 cm bore quads including 2 for dump	5		

WBS			Parameter	Base Value	Unit	Comment
1.	5.	10.	Number of 36 cm bore spreading quadrupoles	4		
1.	5.	10.	Number of 24 x 24 cm dipole correctors	15		
1.	5.	10.	Number of 36x36 cm spreading correctors	4		
1.	5.	10.	Expected RTBT dipole magnetic field errors +/-	0.1	%	Integrated at full acceptance
1.	5.	10.	Expected RTBT quadrupole magnetic field errors +/-	0.1	%	Integrated at full acceptance
1.	5.	10.	Expected RTBT corrector magnetic field errors +/-	1.0	%	Integrated at full acceptance
1.	5.	10.	Magnet offset rms alignment tolerance	0.1	mm	
1.	5.	10.	Magnet pitch and yaw rms alignment tolerance	1	mrad	
1.	5.	10.	Magnet roll rms alignment tolerance	1	mrad	Extraction and RTBT
1.	5.	10.	Number of dipole PS	1		2000A-50V and 900A-80V
1.	5.	10.	Number of quadrupole PS	21		700A-50V to 800A-120V
1.	5.	10.	Number of corrector bipolar PS	19		20 A and 30 V
1.	5.	7.	**RTBT DIAGNOSTICS**			
1.	5.	7.	Number of beam position monitors	17		
1.	5.	7.	Number of beam loss monitors	43		Fast and slow monitors, includes extraction dump
1.	5.	7.	Number of beam current monitors	5		
1.	5.	7.	Number of profile measurements	8		includes extraction dump
1.	6.		**TARGET SYSTEMS**			
1.	6.		Number of target stations	1		
1.	6.		Number of neutron beam shutters	18		
1.	6.		Number of neutron beam lines	24		
1.	6.		Beam-to-floor distance	1.981	m	78 in
1.	6.		Design power level on target	2 MW		1st Target module designed for 1 MW
1.	6.	1.	**TARGET ASSEMBLIES**			
1.	6.	1.	Front cross section of target VxH	104x 399	mm	
1.	6.	1.	Beam spot size on target VxH	70x200	mm	
1.	6.	1.	Tolerance on beam centroid H&V	+/- 2	mm	
1.	6.	1.	Normal peak current density	0.25	A/m^2	for 2 MW beam power
1.	6.	1.	Normal time ave power within beam spot	90	%	
1.	6.	1.	Time ave current density over beam spot	0.143	A/m^2	(2MW beam power)
1.	6.	1.	Normal single pulse peak density	$2.6x10^{16}$	$protons/m^2$	
1.	6.	1.	Off normal single pulse density	$3.2x10^{16}$	$protons/m^2$	For 2 pulses max
1.	6.	1.	Unscheduled beam off > 5s	50	per day	
1.	6.	1.	Unscheduled beam off >300 s	10	per day	
1.	6.	1.	Target material	Hg		Hg inventory < 2.0 cubic m
1.	6.	1.	Hg nominal operating temperature	60 - 90	deg C	(2MW beam power)
1.	6.	1.	Hg target nominal operating pressure	0.3	MPa	
1.	6.	1.	Hg power loading	1.2	MW	(2MW beam power)
1.	6.	1.	Shell material	316 SS LN		
1.	6.	1.	Shell temperature	<200	deg C	
1.	6.	1.	Shroud material	316 SS LN		
1.	6.	1.	Shroud cooling	light water		
1.	6.	1.	Target plug material	Fe-alloy, water, SS		

WBS			Parameter	Base Value	Unit	Comment
1.	6.	2.	**AMBIENT MODERATORS**			
1.	6.	2.	Number of moderators	1		
1.	6.	2.	Moderator material	light water		
1.	6.	2.	Position	below target		Upstream
1.	6.	2.	**CRYOGENIC MODERATORS**			
1.	6.	2.	Number	3		
1.	6.	2.	Moderator material	supercritical H		
1.	6.	2.	Position	2 above target and 1 downstream below		
1.	6.	2.	Viewed face	120 x 100	mm	
1.	6.	2.	Pre moderator	light water		
1.	6.	2.	Non grooved surfaces	yes		
1.	6.	2.	Poison upstream top only	Al clad Gd		
1.	6.	2.	Decoupler upstream top only	Cd		
1.	6.	3.	**REFLECTOR ASSEMBLIES**			
1.	6.	3.	Reflector material	Be		
1.	6.	3.	Configuration	nested cylinders		
1.	6.	3.	Coolant	heavy water		
1.	6.	3.	Outer diameter of Be	0.64	m	
1.	6.	4.	**CORE VESSEL**			
1.	6.	4.	Material	316 SS		
1.	6.	4.	Atmosphere	He		At < 0.1 MPa
1.	6.	4.	Proton beam window material	Inconel 718		
1.	6.	4.	Proton beam window coolant	light water		
1.	6.	5.	**TARGET SYSTEM SHIELDING**			
1.	6.	5.	Number of single channel shutters	12		
1.	6.	5.	Number of multi channel shutters	6		
1.	6.	5.	Shutter configuration	ISIS type		
1.	6.	5.	Neutron HxV channel within single shutter	200 x 220	mm	
1.	6.	9.	**BEAM DUMPS**			
1.	6.	9.	Number of beam dumps	3		
1.	6.	9.	Tolerance on beam center	+/- 50	mm	
1.	6.	9.	Atmosphere	He		At 0.1 Mpa (under evaluation)
1.	6.	9.	Reentrant	yes		
1.	6.	9.	**LINAC DUMP**			
1.	6.	9.	Beam stop material	steel		
1.	6.	9.	Shielding material	Fe alloy		
1.	6.	9.	Cooling mechanism	passive		
1.	6.	9.	Maximum power	≤ 7.5	kW	
1.	6.	9.	Operational hours per year	500	h	
1.	6.	9.	Beam size	60	mm	FWHM
1.	6.	9.	Pulse peak density at 60 Hz	2.3×10^{14}	ppp/m^2	
1.	6.	9.	Pulse peak density at 1 Hz	1.4×10^{16}	ppp/m^2	

WBS			Parameter	Base Value	Unit	Comment
1.	6.	9.	**RING INJECTION DUMP**			
1.	6.	9.	Beam stop material	Cu		
1.	6.	9.	Shielding material	Fe alloy		
1.	6.	9.	Cooling mechanism	forced light water		
1.	6.	9.	Maximum power	150	kW	
1.	6.	9.	Operational hours per year	5000	h	
1.	6.	9.	Beam size	100	mm	>90% beam particles within this radius of dump center
1.	6.	9.	Pulse peak density	5.0×10^{15}	ppp/m^2	
1.	6.	9.	**RING EXTRACTION DUMP**			
1.	6.	9.	Beam stop material	steel		
1.	6.	9.	Shielding material	Fe alloy		
1.	6.	9.	Cooling mechanism	passive		
1.	6.	9.	Maximum power	$\leq$ 7.5	kW	
1.	6.	9.	Operational hours per year	500	h	
1.	6.	9.	Beam size	100	mm	FWHM
1.	6.	9.	Pulse peak density at 60 Hz	3.8×10^{13}	ppp/m^2	
1.	6.	9.	Pulse peak density at 1 Hz	2.3×10^{15}	ppp/m^2	
1.	7.		**NEUTRON INSTRUMENTATION**			
1.	7.	4.	**High Resolution Backscattering Spectrometer**			
1.	7.	4.	Beam Line	2		
1.	7.	4.	Moderator location	top-upbeam		
1.	7.	4.	Moderator material	liquid H2		
1.	7.	4.	Moderator coupling	decoupled		
1.	7.	4.	Moderator-sample distance	84	m	
1.	7.	5.	**Magnetism Reflectometer**			
1.	7.	5.	Beam Line	4a		
1.	7.	5.	Moderator location	top downbeam		
1.	7.	5.	Moderator material	liquid H2		
1.	7.	5.	Moderator coupling	coupled		
1.	7.	5.	Moderator-sample distance	17	m	
1.	7.	5.	Sample-detector distance	2	m	
1.	7.	6.	**Liquids Reflectometer**			
1.	7.	6.	Beam Line	4b		
1.	7.	6.	Moderator location	top downbeam		
1.	7.	6.	Moderator material	liquid H2		
1.	7.	6.	Moderator coupling	coupled		
1.	7.	6.	Moderator-sample distance	13	m	
1.	7.	6.	Sample-detector distance	1.5	m	
1.	7.	8	**Small Angle Scattering Spectrometer**			
1.	7.	8	Beam Line	6		
1.	7.	8	Moderator location	top downbeam		
1.	7.	8	Moderator material	liquid H2		
1.	7.	8	Moderator coupling	coupled		
1.	7.	8	Moderator-sample distance	14	m	

WBS			Parameter	Base Value	Unit	Comment
1.	7.	8	Sample-detector distance	1-4	m	
1.	7.	10	**Powder Diffractometer**			
1.	7.	10	Beam Line	11a		
1.	7.	10	Moderator location	top upbeam		
1.	7.	10	Moderator material	liquid H2		
1.	7.	10	Moderator coupling	decoupled		
1.	7.	10	Moderator-sample distance	60	m	
1.	7.	10	Sample-detector distance	2-5	m	
1.	9.		**CONTROLS**			
1.	9.		Macropulse rate	subharm of 60	Hz	
1.	9.		Single macropulse capability	yes		
1.	9.		Macropulse variable length	0.1 ms to 1 ms		
1.	9.		Linac beam ramp up	variable		
1.	9.		Chopper variable beam pulse length	645 to 100	ns	
1.	9.		Chopper variable gap length	100 to 930	ns	
1.	9.		Single mini (or turn) pulse capability	yes		