CR-021: ILC-91 (Z-pole) AC Power

Review Report
focusing on ML RF & Cryogenics Power

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Review Panel

To be reported to IDT-WG2 meeting, 2022-04-19

Outline

- Introduction
- RF Power Evaluation
- Cryogenics Power Evaluation
- Summary

Summary of CR-021, submitted by Benno List : focusing on ILC-91 ML AC-Power Estimates Updated

CHANGE REQUEST NO. ILC-CR-0021	EDMS No: D0000000xxxxxxx	Created: 23-06-2020 Last modified: 11.1.2022

	250-A	250-A Lx2	91	91 Lx2	91 e driven
Rep-Rate / Hz	5	5	3.7	3.7	5
Bunches / Pulse	1312	2625	1312	2625	1312
Lumi / 10^{34}	1.35	2.7	0.21	0.41	0.28
Gradient / MV/m	31.5	31.5	8.8	8.8	8.8
Q_0/1E10	1.0	1.0	1.0	1.0	1.0
ML E-gain / GeV	220	220	61.2	61.2	61.2
ML RF / MW	24.4	25.9	13.0	19.3	4.8
ML Cryo / MW	15.4	13.1	10.4	11.5	7.1
ML Power / MW	50.1	53.5	30.9	39.3	17.4
e- Src / MW	4.9	5.6	5.5	6.6	4.5
e+ Src / MW	9.3	10.2	9.0	9.6	14.0
DR / MW	14.2	22.2	15.7	22.2	14.2
RTML / MW	10.4	13.3	10.9	14.1	9.2
BDS / MW	9.3	9.3	9.3	9.3	9.3
Dumps / MW	1.2	1.2	1.2	1.2	1.2
IR / MW	5.8	5.8	5.8	5.8	5.8
Campus / MW	2.7	2.7	2.7	2.7	2.7
Gen. Margin/MW	3.3	4.0	1.8	2.1	2.3
Total	111	138	93	113	81

e+ Src (91 e driven) → **24.8** See P9.

Total (91 e driven) → **91.8**

Boundary condition in CR-021, for Main Linac (ML) RF power

- The ML RF power is calculated from the **RF power** transferred **to the beam**, plus the power needed **to fill the cavities**, divided by the wall plug to beam efficiency of **43%**. For the TDR, the ML RF power amounts to 52.1MW (**32%** of the total **163.8MW**).
- The operation at **reduced gradient leads** to operation of klystrons at lower than nominal power, which leads to a **reduction in efficiency**.
- For ML operation for with gradients **alternating between positron production and collision modes,** the external Q of the couplers is set to the matched value at high gradient (Q_{ext} = 5.5E6), leading to a mismatch at lower gradient. This **increases the fill time** in collision mode for the electron beam from 259 (171) ns for the positron beam to 329 (217) ns for the electron beam at 1312 (2625) bunches.
- For an **electron driven** source, both, electron and positron MLs will operate at **matched Q**.

ML Cryo power

- The ML cryogenic power is calculated in the same way **as in ILC-CR-0018** (w same efficiency in smaller cooling power operation → needs to be studied more)

ML Conventional systems power

- The power consumption of conventional systems (heating and ventilation etc) is calculated in the same way as in the TDR.

Outline

- Introduction
- **RF Power Evaluation**
- Cryogenics Power Evaluation
- Summary

CR-21 Power Estimate for Z-pole Operation

➢History

- ✓CR-18 Updated power estimate for ILC250 in May 2019
- ✓CR-19 Luminosity for operation at the Z-pole in Jan.2020
  - 3.7+3.7Hz
- ✓CR-21 Power estimate for Z-pole operation
  - Original request in June 2020 by Benno
  - Revised request in Jan. 2022 by Benno
  - Based on the configuration defined by CR-18 and 19

RF-Related Issues

- **Complication comes from the additional electron beam to create positron**
  a. Positron beam for collision (45.6GeV)
  b. Electron beam for collision (45.6GeV)
  c. Electron beam for positron creation (128GeV)
- **CR-19 adopted**
  - ✓ Low gradient (8.76 MV/m) for (a) and (b)
    - The scheme with full gradient (31.5 MV/m) followed by RF-empty cavities is impossible (fast detuning, quadrupole)
  - ✓ 3.7+3.7Hz for electron main linac
    - Then, the electron ML RF power consumption (nearly) is the same as in E_{CM}=250GeV case
  - ✓ Matched Q_L for (a) and (c), but unmatched for (b)
    - Cannot change Q_L at 3.7Hz
- **This configuration is adopted in the revised change request**
  - ✓ Revised request also includes the e-Driven positron source
- **I basically agree to this updated request**

RF-Related Parameters

		1312 bunches			2625 bunches			e-driven	
		(a) e+	(b) e-	(c) e-	(a) e+	(b) e-	(c) e-	e+	e-
		for coll.	for coll.	for e+	for coll.	for coll.	for e+		
Rep. rate	Hz	3.7	3.7	3.7	3.7	3.7	3.7	5	5
Gradient	MV/m	8.76	8.76	31.5	8.76	8.76	31.5	8.76	8.76
Acceleration in ML	GeV	30.6	30.6	113	30.6	30.6	113	30.6	30.6
matched QL	`10^6	1.52	1.52	5.46	1.01	1.01	3.61	1.52	1.52
chosen QL	`10^6	1.52	5.46	5.46	1.01	3.61	3.61	1.52	1.52
beam pulse length	ms	0.727			0.961			0.727	
fill time	ms	0.259	0.329	0.93	0.171	0.217	0.614	0.259	0.259
RF pulse length	ms	0.986	1.056	1.657	1.132	1.178	1.575	0.986	0.986
(klystron efficiency)	%	48	53	67	48	53	67	67	67
AC power for ML RF	MW	1.89	2.03	9.30	3.06	3.18	13.37	2.38	2.38
AC power for ML RF sum	MW	13.22			19.61			4.76	

RF-Related Parameters (continued)

- **Caveats**
  - It is very hard to talk about percent-level accuracy. For example,
  - Klystron efficiency is significantly lower than 67% used for 250GeV case. It is estimated to be ~53% (or ~48% for e+ beam) but almost out of the range of Fig.3.31 (klystron efficiency as a function of the voltage) in TDR. (By the way the modulator efficiency in CR-19 was wrong. Corrected by Benno.)
  - Off-crest angle is 5 degrees in 31.5MV/m case, but it must be much larger in 8.8MV/m case (over 10 degrees)
- **The updated CR is reasonable within this accuracy**
  - Minor but obvious correction due to 3GeV overhead for positron production is included in this change review.

Other new inputs

- **Case of the e-driven positron source**

  - ✓Positron source power for 1312 bunches = **24.8 MW** (by T. Omori, Jan.17, 2022). The number 14.0 MW in the updated CR is to be replaced.

Outline

- ➢Introduction
- ➢RF Power Evaluation
- ➢**Cryogenics Power Evaluation**
- ➢Summary

How to evaluate the ML Cryogenics AC Power for ILC-91

- **References** for cryogenics AC power estimate
  - ILC500 (TDR) in 2013
  - ILC-250 (Higgs): CR-18 in 2019
  - ILC-91 (Z-pole): CR-19 in 2020, and CR-21 in 2020-2022

- **Process** for estimating the cryogenics power for ILC250 and ILC91
  - Static load: kept constant
  - Dynamic load: scaled (next page) as functions of Gradient (G), Q_0-value, RF pulse-duration, Linac length (L) etc.,
    - RF load (go to beam),
    - Cryogenics loads
      - Input coupler load
      - HOM-coupler, HOM-absorber/beam-pipe, HOM-cavity/2K-structure,
      - CLs for SC magnet (missing, although being relatively small)

ILC ML, Average Heat Loads / CM

Table 3.9
Average heat loads per module in a ML unit, for the baseline parameter in Table 3.1. All values are in watts [27].

	2 K		5–8 K		40–80 K	
	Static	Dynamic	Static	Dynamic	Static	Dynamic
RF Load		8.02				
Radiation Load			1.41		32.49	
Supports	0.60		2.40		18.0	
Input coupler	0.17	0.41	1.73	3.06	16.47	41.78
HOM coupler (cables)	0.01	0.12	0.29	1.17	1.84	5.8
HOM absorber	0.14	0.01	3.13	0.36	-3.27	7.09
Beam tube bellows		0.39				
Current leads	0.28	0.28	0.47	0.47	4.13	4.13
HOM to structure		0.56				
Coax cable (4)	0.05					
Instrumentation taps	0.07					
Diagnostic cable			1.39		5.38	
Sum	1.32	9.79	10.82	5.05	75.04	58.80
Total	11.11		15.87		133.84	

ILC AC Power Scaling

N. Walker
Version 1
19.03.2013

Name : ILC AC power estimate scaling laws

EDMS ID : D00000001015345,A,1,1

Item Type : ILC Document

Status : Released ●

Cryogenic power

The cryogenic power can be divided into static and dynamic parts. Furthermore, the dynamic part several sources which scale differently. The initial values for each contribution are taken as fractions of the total Main Linac load of 32 MW:

Source	MW	%	scaling law *From C. Adolphsen*
Static load	11.2	35%	L_{linac}
Dynamic load:			
RF load	13.8	43%	$(G^2/Q_0)(t_{beam} + 1.11\ t_{fill})L_{linac}f_{rep}$
Input coupler	3.8	12%	$G(t_{beam} + 2t_{fill})I_{beam}L_{linac}f_{rep}$
HOM coupler	1.0	3%	$I_{beam}L_{linac}f_{rep}$
HOM absorber	0.3	1%	$n_b N^2 L_{linac}f_{rep}$
HOM (cavity)	1.0	3%	$n_b N^2 L_{linac}f_{rep}$
Beam tube bellows	0.6	2%	$(G^2/Q_0)(t_{beam} + 1.11\ t_{fill})L_{linac}f_{rep}$
Total	32.0	100%	

PDF (stamped) (https://webservices.desy.de/edms/api/v4/downloads/MTIObjectHandle-0002-1~R~xkcj0liadam--mpprdusrmln~q0StmPdf~mpprdusr~~)

ILC500 (TDR) Cryogenics Operation Power

Table 3.11. Main-linac heat loads and cryogenic plant size [34]. Where there is a site dependence, the values for the flat / mountain topographies are quoted respectively. (The primary difference is in the choice the number of cryo-plants, specifically 6 and 5 plants for flat and mountainous topographies respectively.)

		40–80 K	5–8 K	2 K
Predicted module static heat load	(W/module)	75.04	10.82	1.32
Predicted module dynamic heat load	(W/module)	58.80	5.05	9.79
Number of cryomodules per cryogenic unit		156 / 189	156 / 189	156 / 189
Non-module heat load per cryo unit	(kW)	0.7 / 1.1	0.14 / 0.22	0.14 / 0.22
Total predicted heat per cryogenic unit	(kW)	21.58 / 26.40	2.61 / 3.22	1.87 / 2.32
Efficiency (fraction Carnot)		0.28	0.24	0.22
Efficiency in Watts/Watt	(W/W)	16.45	197.94	702.98
Overall net cryogenic capacity multiplier		1.54	1.54	1.54
Heat load per cryogenic unit including multiplier	(kW)	33.23 / 40.65	4.03 / 4.96	2.88 / 3.57
Installed power	(kW)	547/669	797/981	2028 / 2511
Installed 4.5 K equiv	(kW)	2.50 / 3.05	3.64 / 4.48	9.26 / 11.47
Percent of total power at each level		0.16	0.24	0.60
Total operating power for one cryo unit based on predicted heat (MW)			2.63 / 3.24	
Total installed power for one cryo unit (MW)			3.37 / 4.16	
Total installed 4.5 K equivalent power for one cryo unit (kW)			15.40 / 19.01	

Total / ML
10 x 3.24
= 32.4 MW

ILC-500, -250, -91 AC-Plug Powers in Comparison (before Linac L. Fraction Corrections)

From: :LC-TDR-AC-CR021-ay220418.xlsx. 250 GeV 1st stage-ay

	A	B	C	H	I	P	Q	R	S	Z	AA	AB	AC
5	Initial beam ene	15	GeV										
6				configuration (DKS)		Baseline 1.35E34, 5Hz, 1312, DKS				L upgrade 2.7E34, 5Hz, 2625			
7		Ecm	GeV	500		250				250			
8						e+	e-	Totals		e+	e-	Totals	
9		Gradient	MV/m	31.5		31.5	31.5			31.5	31.5		
10		Q0		1.0E+10		1.0E+10	1.0E+10			1.0E+10	1.0E+10		
11		Energy gain	GeV	470		110	110			110	110		
12		Rep. rate	Hz	5		5	5			5	5		
14		Linac length factor		1.0		0.47	0.47	0.94		0.47	0.47	0.94	
15		Linac energy factor		1.0		0.47	0.47			0.47	0.47		
17		Particles per bunch	$x10^{10}$	2.0		2.0	2.0			2.0	2.0		
18		Number of bunches		1312		1312	1312			2625	2625		
19		Average beam power (dump)	MW	10.5		2.9	2.9			5.9	5.9		
20		$\Delta t_b * f_{RR}$		360		360	360			238	238		
21		Δt_b	ns	553.8		553.8	553.8			366.2	366.2		
22		Beam pulse	us	726.6		726.6	726.6			961.2	961.2		
23		Beam current	mA	5.79		5.79	5.79			8.75	8.75		
24		Matched Q_L	$x10^6$	5.5		5.5	5.5			3.6	3.6		
25		Chosen Qext	$x10^6$	5.5		5.5	5.5			3.6	3.6		
26		t_{fill}	us	925.9		925.9	925.9			612.1	612.1		
27		RF pulse length	ms	1.65		1.65	1.65			1.57	1.57		
28		RF to beam P eff.		44%		44%	44%			61%	61%		
30	RF	2x average linac beam power	MW	9.88	9.88	2.31	2.31	4.62		4.63	4.63	9.25	
31		Average RF power	MW	22.5		5.3	5.3			7.6	7.6		
32		AC-RF Efficiency		43%		43%	43%			43%	43%		
33		Total RF AC power	MW	52.13	52.1	12.2	12.2	24.4	21.9%	17.6	17.6	35.1	25.5%
34		Total efficiency		19%		19%	19%			26%	26%		
35		RF power dumped	MW	42.3	42.3	9.9	9.9	19.8		12.9	12.9	25.9	
37	Cryo	Static cryo power	MW	10.5		2.5	2.5			2.5	2.5		
38		RF load		13.2		3.1	3.1			2.9	2.9		
39		Input coupler		3.6		0.8	0.8			1.1	1.1		
40		HOM coupler		0.9		0.2	0.2			0.3	0.3		
41		HOM absorber		0.3		0.1	0.1			0.1	0.1		
42		HOM (cavity)		0.9		0.2	0.2			0.4	0.4		
43		Beam tube bellows		0.6		0.1	0.1			0.1	0.1		
44		Gfac		8.73E-04		4.08E-04	4.08E-04			3.82E-04	3.82E-04		
45		Pfac		1.47E+06		6.86E+05	6.86E+05			8.80E+05	8.80E+05		
46		Bfac		2.62E+04		1.23E+04	1.23E+04			2.46E+04	2.46E+04		
47		Cfac		1.81E+01		8.45E+00	8.45E+00			1.28E+01	1.28E+01		
48		RF dynamic	MW	19.5		4.6	4.6			5.0	5.0		
49		Margin	10%			0.7	0.7			0.7	0.7		
50		Total cryo AC power	MW	30.0	30.0	7.7	7.7	15.4	13.9%	8.2	8.2	16.4	11.9%
52	CF	Emergency load	MW	4.3		1.0	1.2			1.0	1.0		
53		Normal load	MW	12.1		2.8	2.8			3.7	3.7		
54		RF racks	MW	4.7		1.1	1.1			1.1	1.1		
55		NC Magnets and PS	MW	0.9		0.2	0.2			0.2	0.2		
56		Total CF	MW	22.0	22.0	5.1	5.3	10.5	9.4%	6.0	6.0	12.0	
58	Total Main Linac		MW	104.10	104.1	25.1	25.3	50.3	45.2%	31.8	31.8	63.5	46.1%
60	e- source		MW	4.87		4.9				5.6			
61	e+ source		MW	9.32		9.3				10.2			
62	DR (total)		MW	15.72		14.2				22.2			
63	RTML		MW	10.40		10.4				13.3			
64	BDS		MW	12.38		9.3				9.3			
65	Dumps		MW	1.21		1.2				1.2			
66	IR		MW	5.76	59.7	5.8		55.1	54.8%	5.8		67.5	53.9%
68	Man Campus	(Idependent main campus)				2.7		2.7		2.7		2.7	
69	Gen. Margin	(3%. Suggested)				3.3		3.3		4.0		4.0	
71	Grand total		MW	163.8	164	111.4		111		137.7		138	

	AO	AP	AQ	AR	AS	AU	AV	AW	AX	AY	BA	BB	BC	BD
6	Z Pole, 3.7 Hz					Z Pole, 3.7 Hz, 2625 bunch					Z Pole, 3.7 Hz, e driven source			
7	91.2					91.2					91.2			
8	e+	e- (lumi)	e- (e+ prod)	Totals		e+	e- (lumi)	e- (e+ prod)	Totals		e+	e- (lumi)	Totals	
9	8.8	8.8	31.5			8.8	8.8	31.5			8.8	8.8		
10	1.0E+10	1.0E+10	1.0E+10			1.0E+10	1.0E+10	1.0E+10			1.0E+10	1.0E+10		
11	30.6	30.6	110			30.6	30.6	110			30.6	30.6		
12	3.7	3.7	3.7			3.7	3.7	3.7			5	5		
14	0.47	0.47	0.47	0.94		0.47	0.47	0.47	0.94		0.47	0.47	0.94	Problem
15	0.13	0.13	0.47			0.13	0.13	0.47			0.13	0.13		
17	2.0	2.0	2.0			2.0	2.0	2.0			2.0	2.0		
18	1312	1312	1312			2625	2625	2625			1312	1312		
19	0.9	0.9	2.2			1.9	1.9	4.4			1.3	1.3		
20	360	360	360			238	238	238			360	360		
21	553.8	553.8	553.8			366.2	366.2	366.2			553.8	553.8		
22	726.6	726.6	726.6			961.2	961.2	961.2			726.6	726.6		
23	5.79	5.79	5.79			8.75	8.75	8.75			5.79	5.79		
24	1.5	1.5	5.5			1.0	1.0	3.6			1.5	1.5		
25	1.5	5.5	5.5			1.0	3.6	3.6			1.5	1.5		
26	259.0	329.0	930.0			171.0	217.0	614.0			259.0	259.0		
27	0.99	1.06	1.66			1.13	1.18	1.58			0.99	0.99		
28	74%	69%	44%			85%	82%	61%			74%	74%		
30	0.48	0.48	1.71	2.66		0.95	0.95	3.42	5.33		0.64	0.64	1.29	
31	0.6	0.7	3.9			1.1	1.2	5.6			0.9	0.9		
32	34%	34%	43%			37%	37%	43%			37%	37%		
33	1.9	2.0	9.1	13.0	14.0%	3.1	3.2	13.0	19.3	17.1%	2.4	2.4	4.8	5.9%
34	25%	23%	19%			31%	30%	26%			27%	27%		
35	1.4	1.6	7.3	10.3		2.1	2.2	9.6	13.9		1.7	1.7	3.5	
37	2.5	2.5				2.5	2.5				2.5	2.5		x 1/2
38	0.1	0.1	2.3			0.1	0.1	2.1			0.1	0.1		(artificially)
39	0.1	0.1	0.6			0.1	0.1	0.8			0.1	0.1		
40	0.2	0.2	0.2			0.2	0.2	0.2			0.2	0.2		
41	0.1	0.1	0.1			0.1	0.1	0.1			0.1	0.1		
42	0.2	0.2	0.2			0.3	0.3	0.3			0.2	0.2		
43	0.0	0.0	0.1			0.0	0.0	0.1			0.0	0.0		
44	1.35E-05	1.45E-05	3.03E-04			1.53E-05	1.60E-05	2.83E-04			1.82E-05	1.82E-05		
45	6.82E+04	7.59E+04	5.10E+05			1.08E+05	1.16E+05	6.52E+05			9.22E+04	9.22E+04		
46	9.09E+03	9.09E+03	9.09E+03			1.82E+04	1.82E+04	1.82E+04			1.23E+04	1.23E+04		
47	6.25E+00	6.25E+00	6.25E+00			9.46E+00	9.46E+00	9.46E+00			8.45E+00	8.45E+00		
48	0.6	0.6	3.4			0.9	0.9	3.7			0.7	0.7		
49	0.3	0.6				0.3	0.7				0.3	0.3		
50	3.3	7.1		10.4	11.2%	3.7	7.8		11.5	10.2%	3.5	3.5	7.1	8.7%
52	1.0	1.0				1.0	1.0				1.0	1.0		
53	0.4	2.5				0.6	3.4				0.5	0.5		
54	1.1	1.1				1.1	1.1				1.1	1.1		
55	0.2	0.2				0.2	0.2				0.2	0.2		
56	2.7	4.9		7.6		2.9	5.7		8.6		2.8	2.8	5.6	
58	7.9	23.0		30.9	33.3%	9.7	29.7		39.3	34.8%	8.7	8.7	17.4	21.6%
60	5.5					6.6					4.5			
61	9.0					9.6					14.0			
62	15.7					22.2					14.2			
63	10.9					14.1					9.2			
64	9.3					9.3					9.3			
65	1.2					1.2					1.2			
66	5.8			57.4	66.7%	5.8			68.7	65.2%	5.8		58.2	78.4%
68	2.7					2.7					2.7			
69	1.8					2.1					2.3			
71	92.8			93		112.9			113		80.6		81	

Intro | AC Power KCS (US) | AC Power KCS (US) (upgrades) | 250 GeV 1st stage (ay-220418) | 250 GeV 1st stage-ay | 250 GeV 1st stage (2-ay) | Damping Ring | Sheet1 | +

ILC-500, -250, -91 AC-Plug Powers in Comparison (before Linac L. Fraction Corrections)

From: :LC-TDR-AC-CR021-ay220418.xlsx. 250 GeV 1st stage-ay

	A	B	C	H	I	P	Q	R	S
5	Initial beam ene		15 GeV						
6				configuration (DKS)		Baseline 1.35E34, 5Hz, 1312, DKS			
7		Ecm	GeV	500		250			
8						e+	e-	Totals	
9		Gradient	MV/m	31.5		31.5	31.5		
10		Q0		1.0E+10		1.0E+10	1.0E+10		
11		Energy gain	GeV	470		110	110		
12		Rep. rate	Hz	5		5	5		
13									
14		Linac length factor		1.0		0.47	0.47	0.94	
15		Linac energy factor		1.0		0.47	0.47		
16									
17		Particles per bunch	$x10^{10}$	2.0		2.0	2.0		
18		Number of bunches		1312		1312	1312		
19		Average beam power (dump)	MW	10.5		2.9	2.9		
20		$\Delta t_b * f_{DR}$		360		360	360		
21		Δt_b	ns	553.8		553.8	553.8		
22		Beam pulse	us	726.6		726.6	726.6		
23		Beam current	mA	5.79		5.79	5.79		
24		Matched Q_L	$x10^6$	5.5		5.5	5.5		
25		Chosen Qext	$x10^6$	5.5		5.5	5.5		
26		t_{fill}	us	925.9		925.9	925.9		
27		RF pulse length	ms	1.65		1.65	1.65		
28		RF to beam P eff.		44%		44%	44%		
29									
30	RF	2x average linac beam power	MW	9.88	9.88	2.31	2.31	4.62	
31		Average RF power	MW	22.5		5.3	5.3		
32		AC-RF Efficiency		43%		43%	43%		
33		Total RF AC power	MW	52.13	52.1	12.2	12.2	24.4	21.9%
34		Total efficiency		19%		19%	19%		
35		RF power dumped	MW	42.3	42.3	9.9	9.9	19.8	
36									
37	Cryo	Static cryo power	MW	10.5		2.5	2.5		
38		RF load		13.2		3.1	3.1		
39		Input coupler		3.6		0.8	0.8		
40		HOM coupler		0.9		0.2	0.2		
41		HOM absorber		0.3		0.1	0.1		
42		HOM (cavity)		0.9		0.2	0.2		
43		Beam tube bellows		0.6		0.1	0.1		
44		Gfac		8.73E-04		4.08E-04	4.08E-04		
45		Pfac		1.47E+06		6.86E+05	6.86E+05		
46		Bfac		2.62E+04		1.23E+04	1.23E+04		
47		Cfac		1.81E+01		8.45E+00	8.45E+00		
48		RF dynamic	MW	19.5		4.6	4.6		
49		Margin	10%			0.7	0.7		
50		Total cryo AC power	MW	30.0	30.0	7.7	7.7	15.4	
51									
52	CF	Emergency load	MW	4.3		1.0	1.2		
53		Normal load	MW	12.1		2.8	2.8		
54		RF racks	MW	4.7		1.1	1.1		
55		NC Magnets and PS	MW	0.9		0.2	0.2		
56		Total CF	MW	22.0	22.0	5.1	5.3	10.5	
57									
58	Total Main Linac		MW	104.10	104.1	25.1	25.3	50.3	
59									
60	e- source		MW	4.87		4.9			
61	e+ source		MW	9.32		9.3			
62	DR (total)		MW	15.72		14.2			
63	RTML		MW	10.40		10.4			
64	BDS		MW	12.38		9.3			
65	Dumps		MW	1.21		1.2			
66	IR		MW	5.76	59.7	5.8		55.1	
67									
68	Man Campus	(Idependent main campus)				2.7		2.7	
69	Gen. Margin	(3%. Suggested)				3.3		3.3	
70									
71	Grand total		MW	163.8	164	111.4		111	

AV	AW	AX	AY	AZ	BA	BB	BC	BD
…, 3.7 Hz, …5 bunch					Z Pole, 3.7 Hz, e driven source			
…1.2					91.2			
…(lumi)	e- (e+ prod)	Totals			e+	e- (lumi)	Totals	
8.8	31.5				8.8	8.8		
…0E+10	1.0E+10				1.0E+10	1.0E+10		
30.6	110				30.6	30.6		
3.7	3.7				5	5		
…47	0.47	0.94			0.47	0.47	0.94	Problem
0.13	0.47				0.13	0.13		
2.0	2.0				2.0	2.0		
…2625	2625				1312	1312		
1.9	4.4				1.3	1.3		
…238	238				360	360		
…366.2	366.2				553.8	553.8		
…961.2	961.2				726.6	726.6		
8.75	8.75				5.79	5.79		
1.0	3.6				1.5	1.5		
3.6	3.6				1.5	1.5		
…217.0	614.0				259.0	259.0		
1.18	1.58				0.99	0.99		
…82%	61%				74%	74%		
0.95	3.42	5.33			0.64	0.64	1.29	
1.2	5.6				0.9	0.9		
…37%	43%				37%	37%		
3.2	13.0	19.3	17.1%		2.4	2.4	4.8	5.9%
…30%	26%				27%	27%		
2.2	9.6	13.9			1.7	1.7	3.5	
2.5					2.5	2.5		x 1/2 (artificially)
0.1	2.1				0.1	0.1		
0.1	0.8				0.1	0.1		
0.2	0.2				0.2	0.2		
0.1	0.1				0.1	0.1		
0.3	0.3				0.2	0.2		
0.0	0.1				0.0	0.0		
…0E-05	2.83E-04				1.82E-05	1.82E-05		
…6E+05	6.52E+05				9.22E+04	9.22E+04		
…2E+04	1.82E+04				1.23E+04	1.23E+04		
…6E+00	9.46E+00				8.45E+00	8.45E+00		
0.9	3.7				0.7	0.7		
0.7					0.3	0.3		
7.8		11.5	10.2%		3.5	3.5	7.1	8.7%
1.0					1.0	1.0		
3.4					0.5	0.5		
1.1					1.1	1.1		
0.2					0.2	0.2		
5.7		8.6			2.8	2.8	5.6	
29.7		39.3	34.8%		8.7	8.7	17.4	21.6%
					4.5			
					14.0			
					14.2			
					9.2			
					9.3			
					1.2			
					5.8		58.2	78.4%
					2.7			
					2.3			
…12.9		113			80.6		81	

Problem:
L-total
Should be
0.47

← Artificially x ½
To compensate
the problem

Intro | AC Power KCS (US) | AC Power KCS (US) (upgrades) | 250 GeV 1st stage (ay-220418) | 250 GeV 1st stage-ay | 250 GeV 1st stage (Z-ay) | Damping Ring | Sheet1

Some Corrections/Updates suggested

- The Linac Length Factor may be re-defined.
  - Reference:
  - Total ML length for both e+ and e- at ILC500 normalized to be **1**
  - Each e+ and e- Linac Length at ILC 500 becomes → 0.5
  - Each e+ and e- Linac Length at ILC 250 becomes → 0.5 x 0.47 = 0.235

- It is appropriate for further evaluation to be much simple with minimum confusions.

- The final result for the AC power may be kept same/similar.

ILC-500, -250, -91 AC-Plug Powers in Comparison (after Linac Length Corrections)

AY-220418

From: :LC-TDR-AC-CR021-ay220418.xlsx. 250 GeV 1st stage（ay220418)

	A	B	C	H	I	P	Q	R	S	Z	AA	AB	AC
5	Initial beam ene		15 GeV										
6				configuration (DKS)		Baseline 1.35E34, 5Hz, 1312, DKS				L upgrade 2.7E34, 5Hz, 2625			
7		Ecm	GeV	500		250				250			
8						e+	e-	Totals		e+	e-	Totals	
9		Gradient	MV/m	31.5		31.5	31.5			31.5	31.5		
10		Q0		1.0E+10		1.0E+10	1.0E+10			1.0E+10	1.0E+10		
11		Energy gain	GeV	470		110	110			110	110		
12		Rep. rate	Hz	5		5	5			5	5		
13													
14		Linac length factor		1.0		0.23	0.23	0.47		0.23	0.23	0.47	
15		~~Linac energy factor~~		~~1.0~~		~~0.23~~	~~0.23~~	~~0.47~~		~~0.23~~	~~0.23~~		
16													
17		Particles per bunch	$x10^{10}$	2.0		2.0	2.0			2.0	2.0		
18		Number of bunches		1312		1312	1312			2625	2625		
19		Average beam power (dump)	MW	10.5		2.9	2.9			5.9	5.9		
20		$\Delta t_b * f_{DR}$		360		360	360			238	238		
21		Δt_b	ns	553.8		553.8	553.8			366.2	366.2		
22		Beam pulse	us	726.6		726.6	726.6			961.2	961.2		
23		Beam current	mA	5.79		5.79	5.79			8.75	8.75		
24		Matched Q_L	$x10^6$	5.5		5.5	5.5			3.6	3.6		
25		Chosen Qext	$x10^6$	5.5		5.5	5.5			3.6	3.6		
26		t_{fill}	us	925.9		925.9	925.9			612.1	612.1		
27		RF pulse length	ms	1.65		1.65	1.65			1.57	1.57		
28		RF to beam P eff.		44%		44%	44%			61%	61%		
29													
30	RF	2x average linac beam power	MW	9.88	9.88	2.31	2.31	4.62		4.63	4.63	9.25	
31		Average RF power	MW	22.5		5.3	5.3			7.6	7.6		
32		AC-RF Efficiency		43%		43%	43%			43%	43%		
33		Total RF AC power	MW	52.13	52.1	12.2	12.2	24.40	21.9%	17.6	17.6	35.1	26.1%
34		Total efficiency		19%		19%	19%			26%	26%		
35		RF power dumped	MW	42.3	42.3	9.9	9.9	19.78		12.9	12.9	25.9	
36													
37	Cryo	Static cryo power	MW	10.5		2.5	2.5			2.5	2.5		
38		RF load		13.2		3.1	3.1			2.9	2.9		
39		Input coupler		3.6		0.8	0.8			0.5	1.1		
40		HOM coupler		0.9		0.2	0.2			0.3	0.3		
41		HOM absorber		0.3		0.1	0.1			0.1	0.1		
42		HOM (cavity)		0.9		0.2	0.2			0.4	0.4		
43		Beam tube bellows		0.6		0.1	0.1			0.1	0.1		
44		Gfac (RF-G.- f.)		8.73E-04		2.04E-04	2.04E-04			1.91E-04	1.91E-04		
45		~~Pfac (P_Input Coupl)~~		~~1.47E+06~~		~~3.43E+05~~	~~3.43E+05~~			~~1.40E+05~~	~~1.40E+05~~		
46		Bfac (		2.62E+04		6.14E+03	6.14E+03		ILC	1.23E+04	1.23E+04		
47		Cfac		1.81E+01		4.23E+00	4.23E+00			6.39E+00	6.39E+00		
48		RF dynamic	MW	19.5		4.6	4.6			4.4	5.0		
49		Margin	10%			0.7	0.7			0.7	0.7		
50		Total cryo AC power	MW	30.0	30.0	7.7	7.7	15.45	13.9%	7.6	8.2	15.8	11.7%
51													
52	CF	Emergency load	MW	4.3		1.0	1.2			0.5	0.5		
53		Normal load	MW	12.1		2.8	2.8			3.7	3.7		
54		RF racks	MW	4.7		1.1	1.1			0.5	0.5		
55		NC Magnets and PS	MW	0.9		0.2	0.2			0.1	0.1		
56		Total CF	MW	22.0	22.0	5.1	5.3	10.49	9.4%	4.9	4.9	9.7	
57													
58	Total Main Linac		MW	104.10	104.1	25.1	25.3	50.34	45.2%	30.0	30.6	60.6	45.0%
59													
60	e- source		MW	4.87		4.9				5.6			
61	e+ source		MW	9.32		9.3				10.2			
62	DR (total)		MW	15.72		14.2				22.2			
63	RTML		MW	10.40		10.4				13.3			
64	BDS		MW	12.38		9.3				9.3			
65	Dumps		MW	1.21		1.2				1.2			
66	IR		MW	5.76	59.7	5.8		55.06	54.8%	5.8		67.5	55.0%
67													
68	Man Campus	(Idependent main campus)				2.7		2.70		2.7		2.7	
69	Gen. Margin	(3%. Suggested)				3.3		3.32		3.9		3.9	
70													
71	Grand total		MW	163.8	164	111.4		111.42		134.7		135	

	B	AO	AP	AQ	AR	AS	AV	AW	AX	AY	AZ	BB	BC	BD	BE	BF
6		Z Pole, 3.7 Hz					Z Pole, 3.7 Hz, 2625 b					Z Pole, 3.7 Hz, e driven source				
7	Ecm	91.2					91.2					91.2				
8		e+	e- (lumi)	e- (e+ prod)	Totals		e+	e- (lumi)	e- (e+ prod)	Totals		e+	e- (lumi)	Totals		
9	Gradient	8.8	8.8	31.5			17.5	8.8	31.5			17.5	17.5			
10	Q0	1.0E+10	1.0E+10	1.0E+10			1.0E+10	1.0E+10	1.0E+10			1.0E+10	1.0E+10			
11	Energy gain	30.6	30.6	110			30.6	30.6	110			30.6	30.6			
12	Rep. rate	3.7	3.7	3.7			3.7	3.7	3.7			5	5			
13																
14	Linac length factor	0.23	0.23	0.23	0.47		0.23	0.23	0.23	0.47		0.23	0.23	0.47		Corrected
15	~~Linac energy factor~~	~~0.07~~	~~0.07~~	~~0.23~~	~~0.21~~		~~0.13~~	~~0.13~~	~~0.47~~			~~0.13~~	~~0.13~~			
16																
17	Particles per bunch	2.0	2.0	2.0			2.0	2.0	2.0			2.0	2.0			
18	Number of bunches	1312	1312	1312			2625	2625	2625			1312	1312			
19	Average beam power (dump)	0.9	0.9	2.2			1.9	1.9	4.4			1.3	1.3			
20	$\Delta t_b * f_{DR}$	360	360	360			238	238	238			360	360			
21	Δt_b	553.8	553.8	553.8			366.2	366.2	366.2			553.8	553.8			
22	Beam pulse	726.6	726.6	726.6			961.2	961.2	961.2			726.6	726.6			
23	Beam current	5.79	5.79	5.79			8.75	8.75	8.75			5.79	5.79			
24	Matched Q_L	1.5	1.5	5.5			2.0	1.0	3.6			3.0	3.0			
25	Chosen Qext	1.5	5.5	5.5			2.0	3.6	3.6			3.0	3.0			
26	t_{fill}	259.0	329.0	930.0			171.0	217.0	614.0			259.0	259.0			
27	RF pulse length	0.99	1.06	1.66			1.13	1.18	1.58			0.99	0.99			
28	RF to beam P eff.	74%	69%	44%			85%	82%	61%			74%	74%			
29																
30	2x average linac beam power	0.48	0.48	1.71	2.66		0.95	0.95	3.42	5.33		0.64	0.64	1.29		
31	Average RF power	0.6	0.7	3.9			1.1	1.2	5.6			0.9	0.9			
32	AC-RF Efficiency	34%	34%	43%			37%	37%	43%			37%	37%			
33	Total RF AC power	1.9	2.0	9.1	12.97	14.0%	3.1	3.2	13.0	19.3	17.3%	2.4	2.4	4.8	5.9%	
34	Total efficiency	25%	23%	19%			31%	30%	26%			27%	27%			
35	RF power dumped	1.4	1.6	7.3	10.31		2.1	2.2	9.6	13.9		1.7	1.7	3.5		
36																
37	Static cryo power	2.5	2.5				2.5	2.5				2.5	2.5			not, x 1/2
38	RF load	0.1	0.1	2.3			0.5	0.1	2.1			0.6	0.6			
39	Input coupler	0.1	0.1	0.6			0.3	0.1	0.8			0.2	0.2			
40	HOM coupler	0.2	0.2	0.2			0.2	0.2	0.2			0.2	0.2			
41	HOM absorber	0.1	0.1	0.1			0.1	0.1	0.1			0.1	0.1			
42	HOM (cavity)	0.2	0.2	0.2			0.3	0.3	0.2			0.2	0.2			
43	Beam tube bellows	0.0	0.0	0.1			0.0	0.0	0.1			0.0	0.0			
44	Gfac (RF-G.- f.)	6.75E-06	7.27E-06	1.52E-04			3.06E-05	8.00E-06	1.41E-04			3.65E-05	3.65E-05			
45	~~Pfac (P_Input Coupl)~~	~~3.41E+04~~	~~3.79E+04~~	~~2.55E+05~~			~~1.06E+05~~	~~5.79E+04~~	~~3.26E+05~~			~~9.22E+04~~	~~9.22E+04~~			
46	Bfac (	4.54E+03	4.54E+03	4.54E+03			9.09E+03	9.09E+03	9.09E+03			6.14E+03	6.14E+03			
47	Cfac	3.13E+00	3.13E+00	3.13E+00			4.73E+00	4.73E+00	4.73E+00			4.23E+00	4.23E+00			
48	RF dynamic	0.6	0.6	3.4			1.4	0.9	3.5			1.3	1.3			
49	Margin	0.3	0.6				0.4	0.7				0.4	0.4			
50	Total cryo AC power	3.3	7.1		10.37	11.2%	4.2	7.6		11.8	10.6%	4.1	4.1	8.3	10.3%	
51																
52	Emergency load	1.0	1.0				0.5	1.0				0.5	1.0			
53	Normal load	0.4	2.5				0.6	3.4				0.5	0.5			
54	RF racks	1.1	1.1				0.5	0.5				0.5	0.5			
55	NC Magnets and PS	0.2	0.2				0.1	0.1				0.1	0.1			
56	Total CF	2.7	4.9		7.57		1.8	5.0		6.8		1.7	2.2	3.8		
57																
58	Total Main Linac	7.9	23.0		30.91	33.3%	9.1	28.8		37.9	34.0%	8.2	8.7	16.8	21.0%	
59																
60	e- source	5.5					6.6					4.5				
61	e+ source	9.0					9.6					14.0				
62	DR (total)	15.7					22.2					14.2				
63	RTML	10.9					14.1					9.2				
64	BDS	9.3					9.3					9.3				
65	Dumps	1.2					1.2					1.2				
66	IR	5.8			57.35	66.7%	5.8			68.7	66.0%	5.8		58.2	79.0%	
67																
68	Man Campus	2.7					2.7					2.7				
69	Gen. Margin	1.8					2.1					2.3				
70																
71	Grand total	92.8			92.77		111.5			111		80.0		80		

Intro | AC Power KCS (US) | AC Power KCS (US) (upgrades) | 250 GeV 1st stage (ay-220418) | 250 GeV 1st stage-ay | 250 GeV 1st stage (2-ay) | Damping Ring | Sheet1 | +

SCQ current lead thermal load evaluation (1/2)

TDR-III-2, Table 3.9. Average heat load [W]/CM in a ML-unit (3-CM) for the baseline parameter in Table 3.1.

	2 K		5–8 K		40–80 K	
	Static	Dynamic	Static	Dynamic	Static	Dynamic
RF Load		8.02				
Radiation Load			1.41		32.49	
Supports	0.60		2.40		18.0	
Input coupler	0.17	0.41	1.73	3.06	16.47	41.78
HOM coupler (cables)	0.01	0.12	0.29	1.17	1.84	5.8
HOM absorber	0.14	0.01	3.13	0.36	-3.27	7.09
Beam tube bellows		0.39				
Current leads	0.28	0.28	0.47	0.47	4.13	4.13
HOM to structure		0.56				
Coax cable (4)	0.05					
Instrumentation taps	0.07					
Diagnostic cable			1.39		5.38	
Sum	1.32	9.79	10.82	5.05	75.04	58.80
Total	11.11		15.87		133.84	

0.56 0.94 8.26

		2K	5-8K	40-80K	ToTal	Fraction
T. Efficiency		702.98	197.94	16.45		
<SCM>//CM	W	0.56	0.94	8.26		
SCM AC-Power/ CM	kW	0.394	0.186	0.136	0.716	0.054
Cryo-Total/CM	W	11.11	15.87	133.04		
Total AC-Power/CM	kW	7.810	3.141	2.189	13.141	1

Heat load Fraction:

- SCM/Total-Cryog = ~0.05
- Total-Cryog / Total-ILC : < 0.2

→SCM/Total-ILC :< ~ 1 %

→SCM thermal load may be absorbed within 'general margin of AC power = ~ a few %.

	250-A	250-A Lx2	91	91 Lx2	91 e driven
Rep-Rate / Hz	5	5	3.7	3.7	5
Bunches / Pulse	1312	2625	1312	2625	1312
Lumi / 10^{34}	1.35	2.7	0.21	0.41	0.28
Gradient / MV/m	31.5	31.5	8.8	8.8	8.8
Q_0/1E10	1.0	1.0	1.0	1.0	1.0
ML E-gain / GeV	220	220	61.2	61.2	61.2
ML RF / MW	24.4	25.9	13.0	19.3	4.8
ML Cryo / MW	15.4	13.1	10.4	11.5	7.1
ML Power / MW	50.1	53.5	30.9	39.3	17.4
e- Src / MW	4.9	5.6	5.5	6.6	4.5
e+ Src / MW	9.3	10.2	9.0	9.6	14.0
DR / MW	14.2	22.2	15.7	22.2	14.2
RTML / MW	10.4	13.3	10.9	14.1	9.2
BDS / MW	9.3	9.3	9.3	9.3	9.3
Dumps / MW	1.2	1.2	1.2	1.2	1.2
IR / MW	5.8	5.8	5.8	5.8	5.8
Campus / MW	2.7	2.7	2.7	2.7	2.7
Gen. Margin/MW	3.3	4.0	1.8	2.1	2.3
Total	111	138	93	113	81

Summary of the ILC-91 Cryogenics Power

Finding and Comments:

- In CR-021, ILC-91 (Z-pole) AC-power estimated by scaling from the ILC-500 (TDR) power estimate.
- We generally agree with the CR-021 values to be appropriate, based on the linear scaling to the beam energy ratio.
- However, it is necessary to evaluate more in detail for the cryogenics operational efficiency, in partial

  (< ½) capacity operational mode, resulting in lower efficiency and requiring more AC power.

Recommendations:

- **Improve** the scaling process, in Excel calculations, with a proper fraction of half ML length (0.235),
  - For straight-forward power estimates in each sub-systems,
- **Consider/resume** ML SCM (Q & D) power for CLs (≤ 1 % of total AC power),
  - Enabling to be counted within 'margin' in total estimate.
- **Study** more in detail for the possible lower power efficiency in partial cryogenics capacity operation, inevitably required in ILC-91 (because of all the CM string needs to be operated in lower gradient performance).
- Take more redundant "general AC power margin" for enabling to absorb the less efficiency in the cryogenics
  - X 1.5 margin than that of ILC250 (4.5 5

Outline

- Introduction
- RF Power Evaluation
- Cryogenics Power Evaluation
- Summary

ILC-91 AC Power: General Summary

Energy	GeV	250	250 Lx2	91	91 Lx2	91 e driven
Rep-Rate	Hz	5	5	3.7	3.7	5
Bunches	/Pulse	1312	2625	1312	2625	1312
Lumi	10^{34}	1.35	2.7	0.21	0.41	0.28
Gradient	MV/m	31.5	31.5	8.8	8.8	8.8
Q_0	10^{10}	1.0	1.0	1.0	1.0	1.0
ML E-gain	GeV	220	220	61.2	61.2	61.2
ML RF	MW	24.4	25.9	13.0	19.3	4.8
ML Cryo		15.4	13.1	10.4	11.5	7.1
ML-CF		10.3	14.6	7.5	8.5	5.5
ML-sum		50.1	53.5	30.9	39.3	17.4
e- Src		4.9	5.6	5.5	6.6	4.5
e+ Src		9.3	10.2	9.0	9.6	24.8
DR		14.2	22.2	15.7	22.2	14.2
RTML		10.4	13.3	10.9	14.1	9.2
BDS		9.3	9.3	9.3	9.3	9.3
Dumps		1.2	1.2	1.2	1.2	1.2
IR		5.8	5.8	5.8	5.8	5.8
Campus		2.7	2.7	2.7	2.7	2.7
Margin (+SCM)		3.3	4.0	4.3	5.2	4.2
Total	MW	111	128	95	116	93
(Margin/Total)	(%)	(3)	(3)	(4.5)	(4.5)	(4.5)
Note		Updates suggested are underlined				

Notes:

- **General Power estimate**
  - The review panel generally agree with the ILC-91 AC Power estimate given by CR-021, with some comments/advices.
  - **Excel-sheet estimate process may be simplified** and straight forward, by using the practical linac L fraction.
- **ML-RF power**
  - * The AC power related to ML RF is revised based on the configuration defined in CR19 (Z-pole luminosity) and confirmed.
- **ML-Cryogenic**
  - Powers estimate for ILC91 has been confirmed by using the scaling laws in particular for dynamic losses as functions of Gradient, pulse periods, Linac Length etc.
  - ML SC magnet (SCM-CL) AC power (< 1 % of total) is absorbed within general margin.
- **e+ Source**
  - Power estimation for the electron-driven scheme is also added and confirmed.
- **Margin:** includes ML-SCM & General Margin
  - More margin reserved/suggested for ILC-91, at present stage.

Appendix

Reference 1

Summary of Power Loads by ILC-TDR-500 GeV

11.6.4 Electrical

Electrical load tables were compiled for each area and the systems designed. The ML has about 70 % of the total loads. The conventional loads are from the components associated with running support facilities for the experimental equipment and facilities, such as pumps, fans and other mechanical/electrical systems not provided by the experiment. The power-factor value used for equipment sizing is the actual expected, if given, or a 90 % for all other equipment. Table 11.17 shows a summary of the power loads distributed by component and Accelerator section.

Table 11.17 Summary of power loads (MW) by Accelerator section. 'Conventional' refers to power used for the utilities themselves. This includes water pumps and heating, ventilation and air conditioning, (HVAC). 'Emergency' power feeds utilities that must remain operational when main power is lost.

Accelerator section	RF Power	RF Racks	NC magnets & Power supplies	Cryo	Conventional		Total
					Normal load	Emergency load	
e^- source	1.28	0.09	0.73	0.80	1.02	0.16	4.08
e^+ source	1.39	0.09	4.94	0.59	2.19	0.35	9.56
Damping Ring	8.67		2.97	1.45	1.84	0.14	15.08
RTML	4.76	0.32	1.26	part of ML cryo	0.12	0.14	6.59
Main Linac	58.1	4.9	0.914	32	8.10	5.18	109.16
BDS			10.43	0.41	0.24	0.28	11.36
Dumps					1		1.00
IR			1.16	2.65	0.09	0.17	4.07
Total	74.2	5.4	22.4	37.9	14.6	6.4	161

210 ILC Technical Design Report: Volume 3, Part II

ILC-500 (TDR) Cryogenics Plant Power

Table 3.12. ILC cryogenic plant sizes (also includes sources, damping rings and beam delivery section for completeness) [47].

Ref: ILC-TDR-3-II

Area	# of Plants	Installed Plant Size (each) (MW)	Total Installed Power (MW)	Operating Power (each) (MW)	Total Operating Power (MW)
Main Linac + RTML flat/mntn	12 / 10	3.37 / 4.16	40.44 / 41.60	2.63 / 3.24	31.56 / 32.40
Positron Source	1	0.65	0.65	0.35	0.35
Electron Source	1	0.70	0.70	0.48	0.48
Damping Rings	1	1.45	1.45	1.13	1.13
BDS	1	0.41	0.41	0.33	0.33
Experiments	1	1.00	1.00	0.70	0.70
Total	17 / 15		44.65 / 45.81		34.55 / 35.39

Total operating power for one cryo unit based on predicted heat (MW)	3.24	X 10
Total operating power for one cryo unit including uncertainty factor (MW)	3.57	X 10 (applied in ILC250 ~)
Total installed power for one cryo unit (MW)	4.16	
Total installed 4.5 K equivalent power for one cryo unit (kW)	19.01	

Ref: ILCCryoTDP014Oct2912BL.xls, TDR Power DKS

ILC AC-plug Power and CF Fraction

A.Yamamoto. 200703
Update: 211220

in comparison of **ILC-500** (TDR) and **ILC-250** (Baseline)

	ILC-500 Total Power	ILC-500 CF Power (Fraction)	ILC-250 Total Power	ILC-250 CF Power (Fraction)
e- source	4.9	2.0	4.9	2.0
e+ source	9.3	2.3	9.3	2.3
DR	15.7	2.6	14.2	2.4
RTML	10.4	2.0	10.4	2.0
Main Linac (ML)	104.1	16.4	50.3	7.9
BDS	12.4	1.5	9.3	1.1
Beam Dump	1.2	1.2	1.2	1.2
IR	5.8	1.9	5.8	1.9
Main Campus	--	--	2.7	0.5
General Margin	--	--	3.3	0.7
Sum	**164**	**30**	**111**	**22**
References, or Comments	ILC-TDR baseline (2013-6), updated, CR0021 (BL, 200630)	ILC TDR Cost-Rev. Rep. CFS (A. Enomoto, 2013-2-6)	ILC TDR-CR0018, Final, (BL-AY, 19123)	* Personal estimate by AY, scaled from ILC-500 to -250.

Notes: Conventional Facility (CF) Power includes electrical network, cooling-water system, ventilation in acc. tunnel, and emergency power. ML total includes RF and Cryogenics in large fraction.

ILC250 Parameter Updates: References

reported by Shin Michizono, at SnowMass'21, AF-EF Joint Meeting Day 1, 24 June, 2020.

LINEAR COLLIDER COLLABORATION

References

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[6] "Updated power estimate for ILC-250", Dec.2019
https://edmsdirect.desy.de/item/D00000001169675
[7] "Summary of the ILC Advisory Panel's Discussions to Date after Revision" (MEXT, Japan):
http://www.mext.go.jp/component/b_menu/shingi/toushin/__icsFiles/afieldfile/2018/09/20/1409220_2_1.pdf
[8] European Strategy Input and its supporting document
https://ilchome.web.cern.ch/content/ilc-european-strategy-document
https://indico.cern.ch/event/765096/contributions/
https://indico.cern.ch/event/765096/contributions/3295702/
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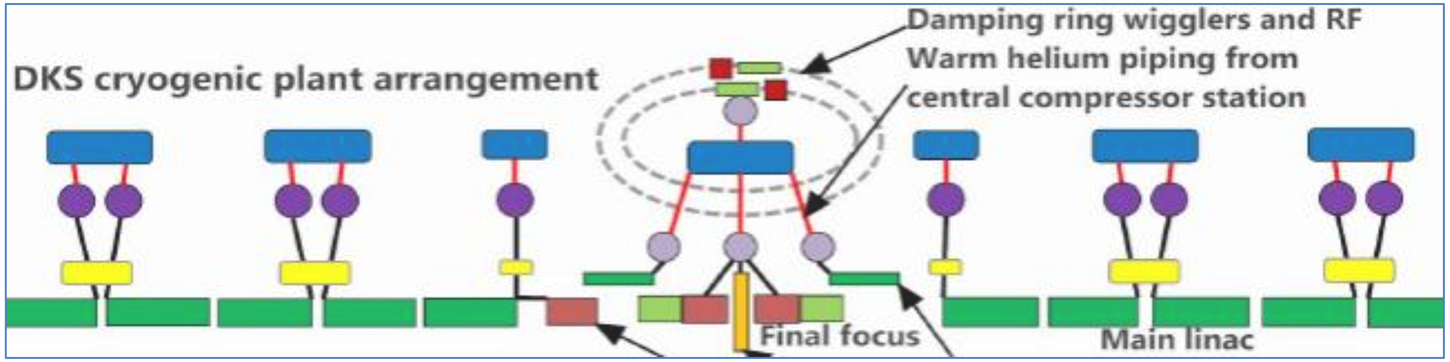
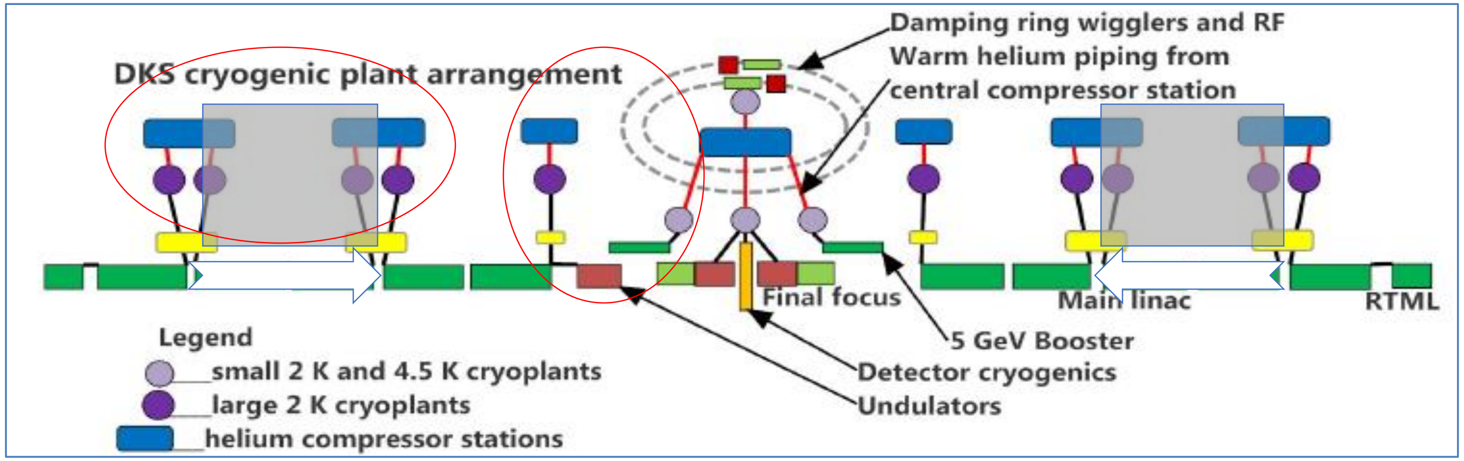
[9] "Green ILC project," http://green-ilc.in2p3.fr/home/ (2018).

ILC Cryog. Configuration to be staged at 250 GeV
Option D (ML installed, downstream)



TDR-2013
Configuration
at 500 GeV
- 5 plants/linac



Staging
at 250 GeV :
3 plants/linac,
although the
cooling power
requirements to
be reduced
down to ~70 %.

ILC Cryogenics System Configuration

T. Peterson, ILCCryTDP-140ct2012BL.xlx, Oct. 14, 2012

26-Jun-12	2 K total heat	5 K total heat	40 K total heat	Installed power	installed power for reference	power ratio	total number of cryogenic plants	total installed plant power
		(Watts per cryomodule, not including other heat)		(MW per cryoplant)	(MW per cryoplant)	new/RDR	of this size	(MW)
for reference: RDR	*11.37*	*14.93*	*153.48*	*4.29*	*4.29*	*1.00*	*10*	*42.9*
for reference: RDR revised	*11.37*	*17.87*	*157.99*	*4.48*	*4.29*	*1.05*	*10*	*44.8*
TDR KCS for ML + RTML	11.11	15.86	133.84	3.37	4.29	0.79	12	40.5
TDR DKS for **ML + RTML**	11.11	15.86	133.84	4.16	4.29	0.97	**10**	41.6
e+ 5 GeV source	9.29	20.20	169.26	0.65	4.29	0.15	1	0.65
e- 5 GeV source	12.19	21.83	195.75	0.70	4.29	0.16	1	0.70

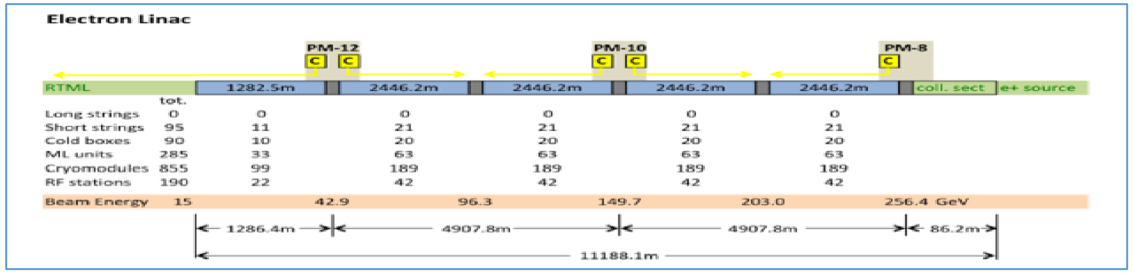
ILC-ML Cryogenics Thermal/Power Balance

T. Peterson, ILC_TDP_CryogenicsCosts-6July2012_gdmod (Version1).xls

		40-80 K	5-8 K	2 K
Predicted module static heat load	(W/module)	75.04	10.82	1.32
Predicted module dynamic heat load	(W/module)	58.80	5.05	9.79
Number of cryomodules per cryogenic unit		189.00	189.00	189.00
Non-module heat load per cryo unit	(kW)	1.10	0.22	0.22
Total predicted heat per cryogenic unit	(kW)	26.40	3.22	2.32
Efficiency (fraction Carnot)		0.28	0.24	0.22
Efficiency in Watts/Watt	(W/W)	16.45	197.94	702.98
Overall net cryogenic capacity multiplier		1.54	1.54	1.54
Heat load per cryogenic unit including multiplier	(kW)	40.65	4.96	3.57
Installed power	(kW)	668.54	981.07	2511.22
Installed 4.5 K equiv	(kW)	3.05	4.48	11.47
Percent of total power at each level		0.16	0.24	0.60
Total operating power for one cryo unit based on predicted heat (MW)				3.24
Total installed power for one cryo unit (MW)				4.16
Total installed 4.5 K equivalent power for one cryo unit (kW)				19.01

Updated: 170724

Staging (250 GeV) effects on the SRF Cryogenic Systems



	MILC	%
e-, 2+	2 x 32.5	2 x 4.8
DR	26.0	3.9
RTML (unit)	38.1 19.1	5.6 (2.8)
ML (unit)	526.9 (58.54)	78.1 (8.6)
BDS	18.4	2.7
Sum	674.6	100

E = 31.5 MV/m, and L-eff = 1.0385 m
+V/cavity = 32.7 MV

+V/st-Cryogenics) = 3 x 21 x 0.8505 = 53.6 GeV
+V/short-string = 2.55 GeV
+V/MLU = 32.71 x 26 = 850.5 MV
Cryogenics unit (short string) length (3 MLU)
= 3 x 37.956+2.5 = 116.368
RF unit (4.5 CM) length = 56.934 m
MLU blength (→3 CM) = 3 x 12.652 = 37.956 m
CM length = 12.652 m (pitch)

		RT ML-BC	ML-CM	PM -12 -u	PM -12 -d	ML-CM		PM -10 -u	PM -10 -d	ML		-u	-d	r	Sum	Cost Down
TDR - 500	Cryo-Cost	19.05 + 29.27			58.54		58.54		58.54		58.54		32.54*		315.02	n/a
	# C-Plant	~ 0.2 + 0.5 = 0.7 → 1			1		1		1		1		> ~ 0.55*		5.5 systems	
	CP-Power	(19 kW @ 4.5 K)			19 kW @ 4.5 K		19 kW @ 4.5 K		19 kW @ 4.5 K		19 kW @ 4.5 K					
	# CM	51	99			189	189			189	189			24	930	
	E. Sum	10	28.1			53.6	53.6			53.6	53.6			5	257.5	

		RT ML-BC	ML-CM	PM -10 -u	PM -12 -d	ML-CM		PM -10 -u	PM -10 -d	ML-CM		PM -8 -u	PM -8 -d	e+ Booster	Sum	
	Cryo-Cost	19.05 + 29.27			---		---		58.54		58.54		32.54*		197.94	0
Stag e- 250 31.5MV/m 1E10	# Cryo-P.	~0.2 + 0.5 = 0.7 → 1			---		---		1		1		~ 0.55		3.5 systems	
	# CM	51	45		---	---	---	---		189	189			24	498	
	E. Sum	10	12.8		---	---	---	---		53.6	53.6			5	135.0	
Stag e- 250 +SRF R&D 35MV/m 1.6E1	Cryo-Cost	58.54									58.54 + 13 (for long distribution)				130	- 68
	# C-Plant	0.7 x (0.2 + 0.05 + 1) = 0.88 → 1 (TL reduction model: relatively lowered to ~ 70%, because of high-Q)									0.7 x (1+0.13) + x= 0.79 + ~0.x → 1				2 systems	
	# CM & (relative TL)	51	4.5		---	---	---	---		189 (132)	189 (132)			24 (17)	457.5	

T. Peterson, ILCCryTDP-140ct2012BL.xlx, Oct. 14, 2012

Tom Peterson
26-Jun-12
This sheet: TDR Power DKS
1 standard cryogenic unit with DKS arrangement into cryo strings and cryo units
Heat loads per attached CM_HeatLoad sheet (sheet 1)
Module length based on Module-9-8-9-21Nov06.xls

ILC Cryogenic Power Estimates

approximate cryogenic unit length (km)
2.434

Total heat load (dynamic plus static) for 9-8-9 RF units, full cryogenic unit

		40 K to 80 K Temperature level (module)	5 K to 8 K Temperature level (module)	2 K Temperature level (module)
Temp in	(K)	40.00	5.0	2.4
Press in	(bar)	16.0	5.0	1.2
Enthalpy in	(J/g)	223.8	14.7	4.383
Entropy in	(J/gK)	15.3	3.9	1.862
Temp out	(K)	80.00	8.0	2.0
Press out	(bar)	14.0	4.0	saturated vapor
Enthalpy out	(J/g)	432.5	46.7	25.04
Entropy out	(J/gK)	19.2	9.1	12.58
		40 K to 80 K	5 K to 8 K	2 K
Predicted module static heat load	(W/module)	75.04	10.82	1.32
Predicted module dynamic heat load	(W/module)	58.80	5.05	9.79
Number of modules per cryo unit (9-8-9-cavity modules)		189.0	189.0	189.0
Total module static heat per cryo unit	(kW)	14.18	2.04	0.25
Total module dynamic heat per cryo unit	(kW)	11.11	0.95	1.85
Non-module heat load per cryo unit	(kW)	1.10	0.22	0.22
Total predicted heat per cryogenic unit	(kW)	26.40	3.22	2.32
Total predicted mass flow per cryo unit	(g/s)	126.49	100.42	112.29
Ideal power based on total estimated heat	(kW)	121.6	152.9	358.7
Heat uncertainty factor on static heat (Fus)		1.10	1.10	1.10
Heat uncertainty factor on dynamic heat (Fud)		1.10	1.10	1.10
Heat load per cryogenic unit including uncertainty	(kW)	29.04	3.54	2.55
Mass flow per cryogenic unit including uncertainty	(g/s)	139.14	110.46	123.52
Weighted ideal power	(kW)	133.7	168.2	394.6
4.5 K equiv weighted power	(kW)	2.0	2.6	6.0
Efficiency (fraction Carnot)		0.28	0.24	0.22
Efficiency in Watts/Watt	(W/W)	16.4	197.9	703.0
Operating power based on predicted heat	(kW)	434.1	637.1	1630.7
Operating power including uncertainty	(kW)	477.5	700.8	1793.7
Overcapacity factor (Fo)		1.40	1.40	1.40
Overall net cryogenic capacity multiplier		1.54	1.54	1.54
Heat load per cryogenic unit including Fus, Fud, and Fo	(kW)	40.65	4.96	3.57
Installed power	(kW)	668.5	981.1	2511.2
Installed 4.5 K equiv	(kW)	3.1	4.5	11.5
Installed 4.5 K equiv per unit length	(W/m)	1.3	1.8	4.7
Percent of total power at each level		16.1%	23.6%	60.4%

Total operating power for one cryo unit based on predicted heat (MW)	3.24
Total operating power for one cryo unit including uncertainty factor (MW)	3.57
Total installed power for one cryo unit (MW)	4.16
Total installed 4.5 K equivalent power for one cryo unit (kW)	19.01
Fraction of largest practical cryoplant per cryogenic unit	0.76

Assumptions:
Module length based on Module-9-8-9-21Nov06.xls
12668 mm slot length for module with magnets and BPM
12668 mm slot length for module without magnets and BPM
189 modules in this cryogenic unit (longest anticipated)
number of modules from cryogenics_parameters_DKS.xlsx

Note: cells highlighted in yellow are independent variables, parameters that are entered

Heat loads per CM_HeatLoad sheet

Add 10 W, 10 W, and 50 W load total for other heat
per cryo box at 2 K, 5 K and 40 K, respectively
times 22 boxes per cryo unit

Heat uncertainty factor is margin for underestimating heat loads

Cryoplant coefficient of performance (W/W)

	40 K - 80 K	5 K - 8 K	2 K	
TESLA TDR:	17	168	588	
XFEL:	20	220	870	
Industrial est:	16.5	200	700	adjusted eff to match these
ILC assumption:	16.4	197.9	703.0	

Overcapacity factor is margin for off-optimal operation and control
Overall multiplier = 1.54 TESLA TDR: 1.50
Vapor density (g/cc) 0.0007936 peak vapor velocity (cm/sec) 308.430253
including uncertainty and overcapacity factors
2 K mass flow with all factors 172.9301808

Operating power includes 1.2 overcapacity factor for control only
Operating power includes 1.2 overcapacity factor for control only
22.01 kW per module

1.7.2.2.1.2	Main Linac cryogenic unit feed boxes (UFB)	8	each	10	$	0.50	5.00	0.9%	One in tunnel at supply end of each cryogenic unit
1.7.2.2.1.3	Main Linac string connecting boxes (SCB)	8	each	176	$	0.40	70.40	12.5%	Between adjacent cryogenic strings
1.7.2.2.1.4	Main Linac cryo unit single end boxes (SEB)	8	each	2	$	0.40	0.80	0.1%	Low energy end of each linac
1.7.2.2.1.5	Main Linac cryo unit double end boxes (DEB)	8	each	2	$	0.50	1.00	0.2%	Between adjacent cryogenic units
1.7.2.2.1.6	Main Linac horizontal transfer lines and cold bypasses	11	m	2560	$	0.008	20.48	3.6%	
1.7.2.2.1.7	Main Linac warm helium gas header	14	km	23	$	0.7160	16.47	2.9%	12" pipe
1.7.2.2.1.8	Undulator cryogenic transfer lines	13	m	300	$	0.001	0.30	0.1%	Undulator is cooled by a ML plant and cooling costs included with ML
1.7.2.2.1.9	Undulator cryogenic distribution and end boxes	9	each	3	$	0.50	1.50	0.3%	
1.7.2.2.2	**RTML cryogenic distribution**						**$ 8.3**	**1.5%**	Reference doc's: Module-9-8-9-21Nov06.xls
1.7.2.2.2.1	RTML RF cryogenic string connecting boxes	8	each	7	$	0.40	2.80	0.5%	
1.7.2.2.2.2	RTML cryogenic transfer lines	11	m	500	$	0.008	4.00	0.7%	
1.7.2.2.2.3	RTML SC magnet connecting boxes	9	each	3	$	0.50	1.50	0.3%	
1.7.2.2.3	**Source cryogenic distribution**						**$ 26.54**	**4.7%**	Each source about 500 m total, with 280 m of modules and 50 m spin rotator
1.7.2.2.3.1	Electron source cryogenic distribution boxes	10	each	1	$	1.000	$ 1.00	0.2%	
1.7.2.2.3.2	Electron source cryogenic end boxes	10	each	6	$	1.000	$ 6.00	1.1%	
1.7.2.2.3.3	Electron source transfer lines	11	m	694	$	0.008	$ 5.55	1.0%	300 m within source, 394 m represents 3.5% reserve tunnel
1.7.2.2.3.4	Electron source warm helium gas header	14	km	1	$	0.7160	$ 0.72	0.1%	
1.7.2.2.3.5	Positron source cryogenic distribution boxes	10	each	1	$	1.000	$ 1.00	0.2%	
1.7.2.2.3.6	Positron source cryogenic end boxes	10	each	6	$	1.00	$ 6.00	1.1%	
1.7.2.2.3.7	Positron source cryogenic transfer lines	11	m	694	$	0.008	$ 5.55	1.0%	300 m within source, 394 m represents 3.5% reserve tunnel
1.7.2.2.3.8	Positron source warm helium gas header	14	km	1	$	0.7160	$ 0.72	0.1%	
1.7.2.2.4	**Damping Ring cryogenic distribution**						**$ 7.00**	**1.2%**	all 4.5 K plus 80 K helium thermal shield
1.7.2.2.4.1	Damping ring cryogenic distribution boxes	9	each	1	$	1.000	$ 1.00	0.2%	one distribution box in tunnel near string ends
1.7.2.2.4.2	Electron damping ring wiggler cryogenic end boxes	9	each	2	$	0.500	$ 1.00	0.2%	one wiggler string
1.7.2.2.4.3	Electron damping ring RF module cryogenic end boxes	9	each	2	$	0.500	$ 1.00	0.2%	one RF cryomodule string
1.7.2.2.4.4	Electron damping ring transfer lines	13	km	1	$	1.000	$ 1.00	0.2%	surface piping from compressors plus tunnel piping and transfer lines
1.7.2.2.4.5	Positron damping ring wiggler cryogenic end boxes	9	each	2	$	0.500	$ 1.00	0.2%	one wiggler string
1.7.2.2.4.6	Positron damping ring RF module cryogenic end boxes	9	each	2	$	0.500	$ 1.00	0.2%	one RF cryomodule string
1.7.2.2.4.7	Positron damping ring transfer lines	13	km	1	$	1.000	$ 1.00	0.2%	surface piping from compressors plus tunnel piping and transfer lines
1.7.2.2.5	**Beam Delivery System cryogenic distribution**						**$ 7.40**	**1.3%**	Assume one IR with push-pull detectors, keeping the RDR estimate
1.7.2.2.5.1	BDS cryogenic distribution systems	10	each	1	$	1.000	$ 1.00	0.2%	
1.7.2.2.5.2	BDS crab cavity cryogenic end boxes	9	each	4	$	0.50	$ 2.00	0.4%	
1.7.2.2.5.3	BDS final focus cryogenic end boxes	9	each	4	$	0.50	$ 2.00	0.4%	
1.7.2.2.5.4	BDS octupole cryogenic end boxes	9	each	4	$	0.50	$ 2.00	0.4%	
1.7.2.2.5.5	BDS transfer lines	13	m	400	$	0.001	$ 0.40	0.1%	
1.7.2.2.5.6									

						Fraction
Main Linac and RTML cryogenic plants	$	**326**	1.23881	$	403.71	60%
Source cryogenic plants	$	29.28	1.1	$	32.21	5%
Damping Ring cryogenic plants	$	15.77	1.1	$	17.34	3%
Beam Delivery System cryogenics	$	7.49	1.23881	$	9.28	1%
Main Linac cryogenic distribution	$	121.9	1.23881	$	151.07	22%
RTML cryogenic distribution	$	8.3	1.23881	$	10.28	2%
Source cryogenic distribution	$	26.54	1.23881	$	32.87	5%
Damping Ring cryogenic distribution	$	7.00	1.23881	$	8.67	1%
Beam Delivery System cryogenic distribution	$	7.40	1.23881	$	9.17	1%
	$	550		$	675	100%

By area system

			Labor (man-hrs)	
Common				
Electron Source				
Positron Source	$	32.543	26,645	4.8%
Damping Rings	$	32.543	26,645	4.8%
RTML	$	26.015	21,300	3.9%
Main Linac	$	38.138	31,226	5.7%
BDS	$	526.928	431,429	78.1%
IR	$	18.443	15,101	2.7%
TOTAL	$	674.610	552,345	100.0%