CFS-ADI Joint Meeting/20140408

Cryogenic Cavern in Mountainous Region - Review

LINEAR COLLIDER COLLABORATION

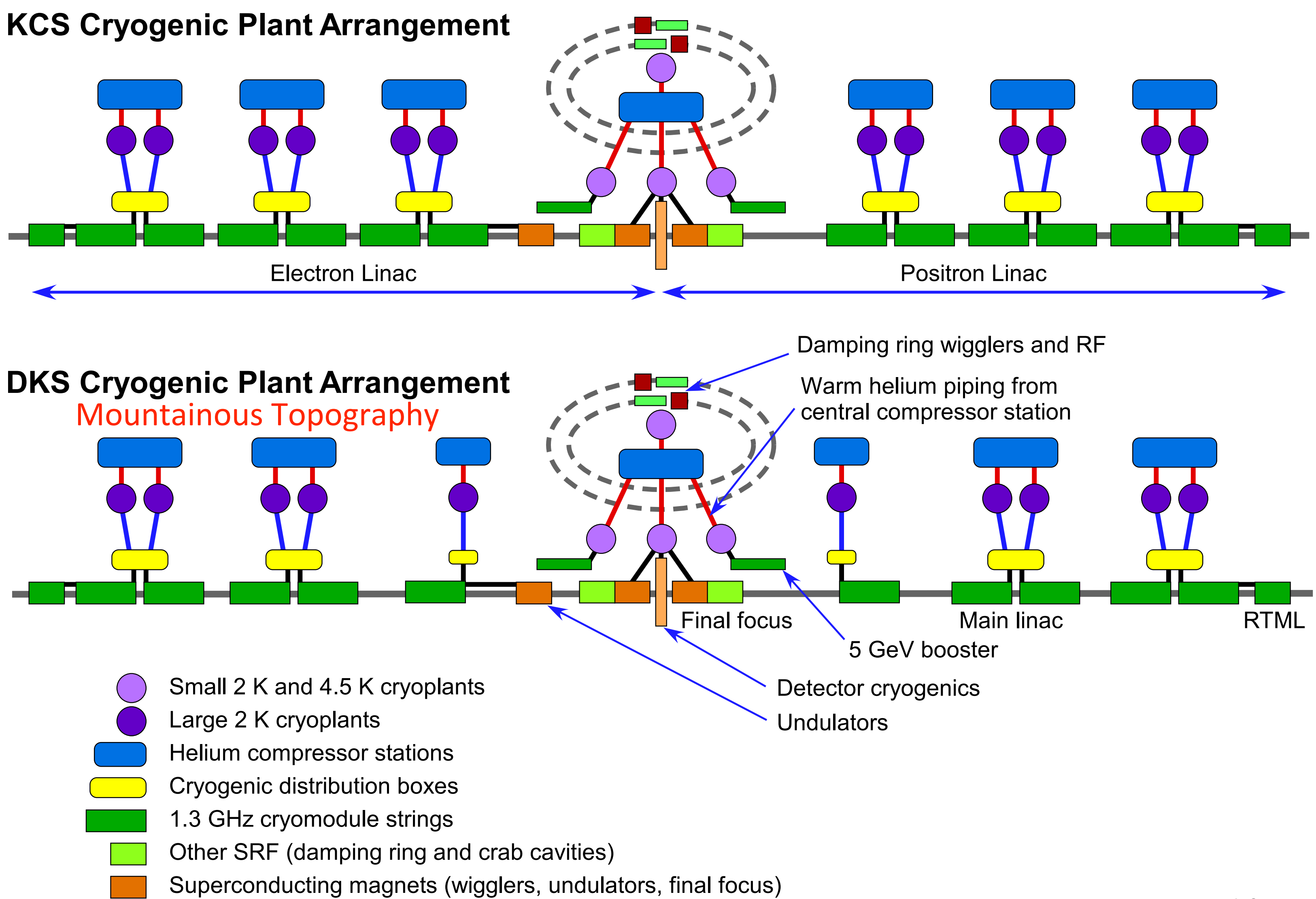
Designing the world's next great particle accelerator

1. Cryogenic system configuration
2. Helium inventory

NAKAI Hirotaka

KEK

Overall Layout for Cryogenic Systems



Cited from ILC-TDR

Main Linac Heat Loads & Cryogenic Plant Sizes

		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	

flat / mountain topographies

Cited from ILC-TDR

CERN-LHC Cryogenic System

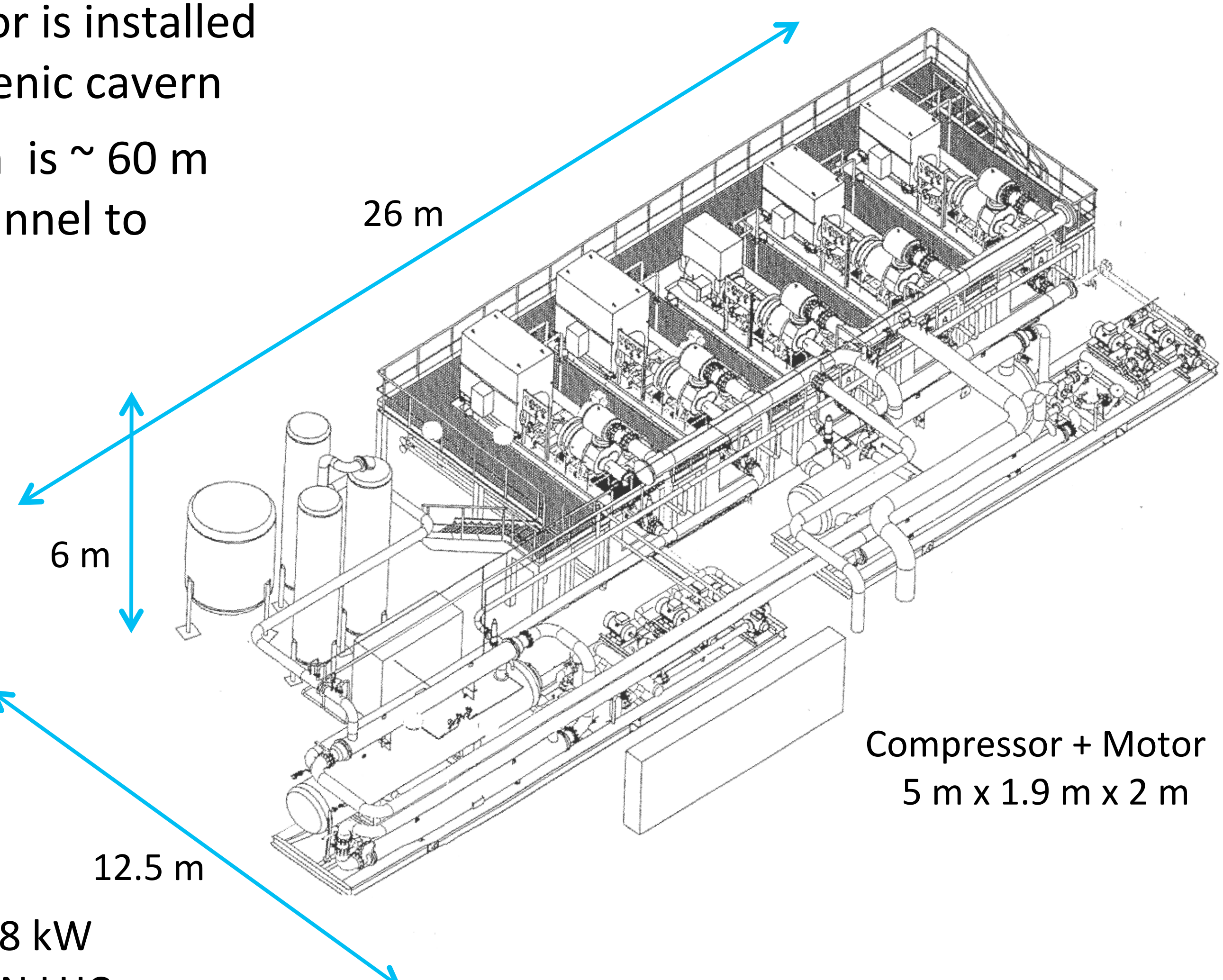
4.5 K refrigerators
(18 kW @ 4.5 K)

1.8 K refrigeration units
(2.4 kW @ 1.8 K)

Ph. Lebrun, Magnet Technology for Fusion Training School, 2009

Main Linac Heat Loads & Cryogenic Plant Sizes

- The helium compressor is installed in far end of the cryogenic cavern
- Location of the cavern is ~ 60 m away from the main tunnel to avoid the vibration



Helium compressors for 18 kW
Helium Refrigerator / CERN LHC

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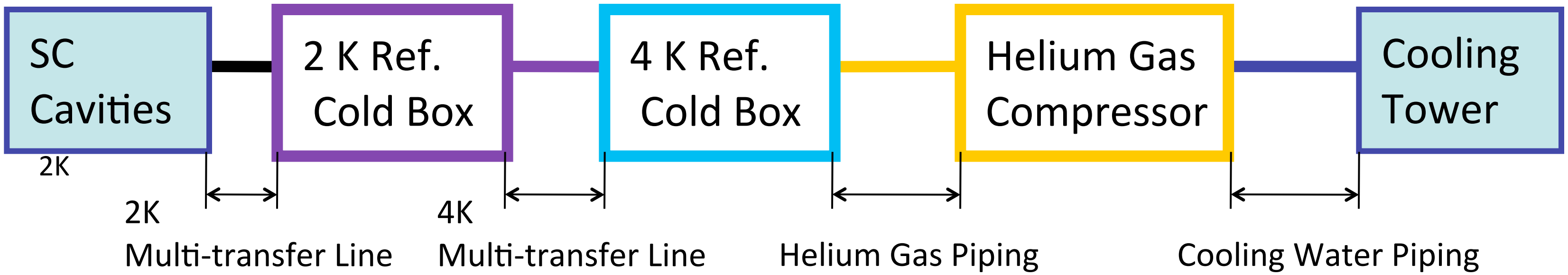
CERN-LHC 18 kW Refrigerator Compressors

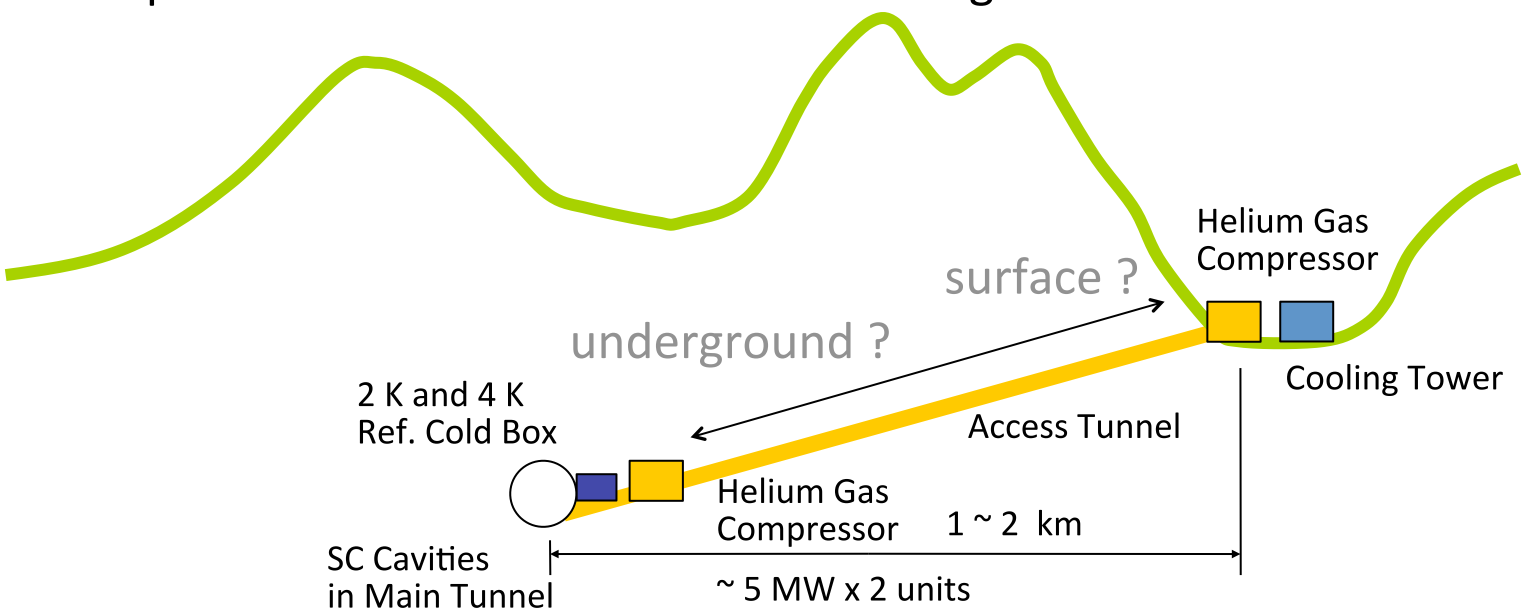
Ph. Lebrun, Magnet Technology for Fusion Training School, 2009

Conceptual Design of Cryogenic System 1



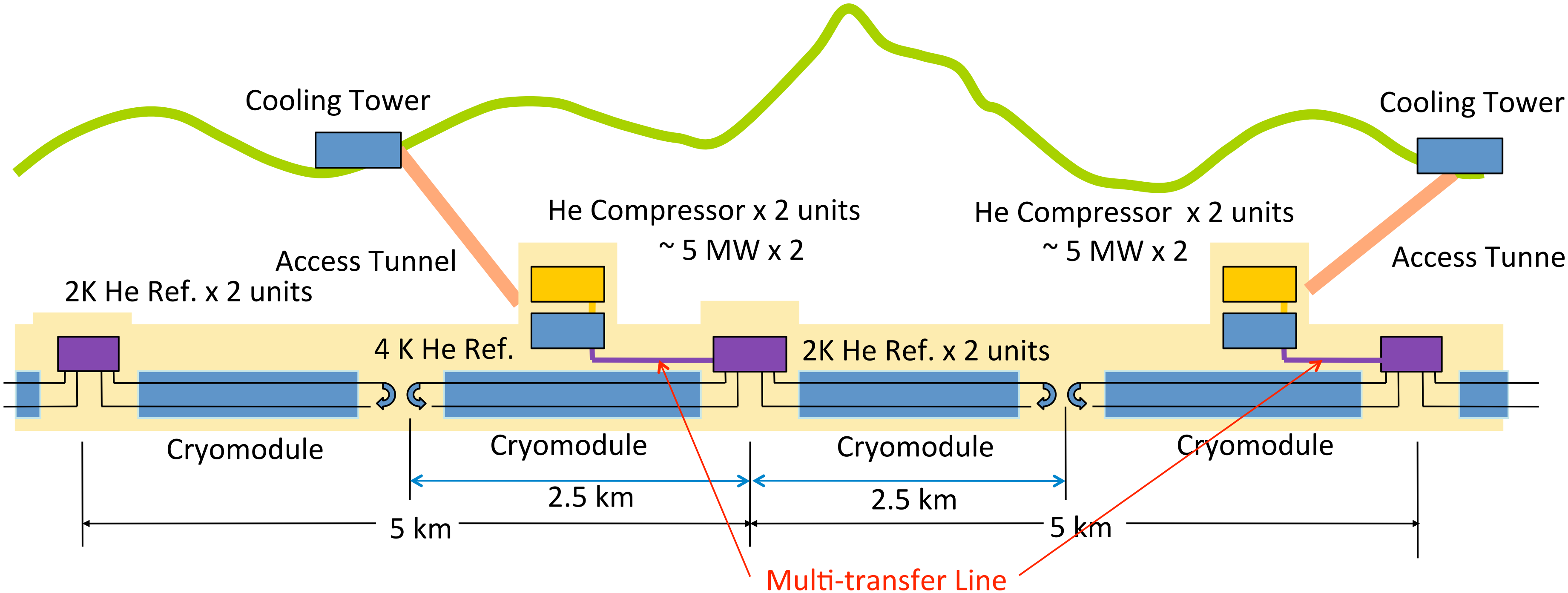
There are many option of layout of main components:

- 4K cold boxes will be installed in the large caverns at the end of access.
- Compressor units will be installed in underground tunnel.



Hosoyama, International Workshop on Linear Colliders 2010

Conceptual Design of Cryogenic System 2



- 4K cold boxes will be installed in the large caverns at the end of access.
- Two 2K cold boxes must be installed in the caverns at 5 km intervals and each 2K cold box supports cooling of ~2.5 km long cryogenic unit.
- Long multi-transfer line must be installed in the main tunnel to connect 2K and 4K refrigerators.
- We must carry in the 2K cold box and distribution box through main tunnel.

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Main Linac Helium Inventory

Volumes	modules	Helium (liquid liters equivalent)	Tevatron Equiv.	LHC Equiv.
One module	1	346		
String (flat)	12	4153	0.07	
String (mountainous)	9	3115	0.05	
Cryogenic unit (flat)	156	54 000	0.9	0.054
Cryogenic unit (mountainous)	189	65 400	1.1	0.065
ILC Main Linacs	1825	632 000	10.5	0.63

Cited from ILC-TDR

Helium Inventory Consideration

Required Liquid Helium ~ 650,000 L

1) Storage as Gas

Standard gas storage tank 100 m^3 (Diameter 3 m x Length 15 m)

1 L Liquid helium ---> 0.7 Nm^3 Gas helium

100 m^3 x 18 (pressure ratio) = 1800 Nm^3 ---> ~ 2,600 L/unit

~ 100 m^3/unit x 250 units

2) Storage as Liquid

Liquid helium Dewar ~ 50,000 L (Diameter 2.5 m x Length 10 m)

~ 50,000 L/unit x 13 units

Vaporization loss:

50,000 L x 0.5 %/day = 250 L/day ~10 L/hr

(Small refrigerator can be used as "Baby-Sitter")

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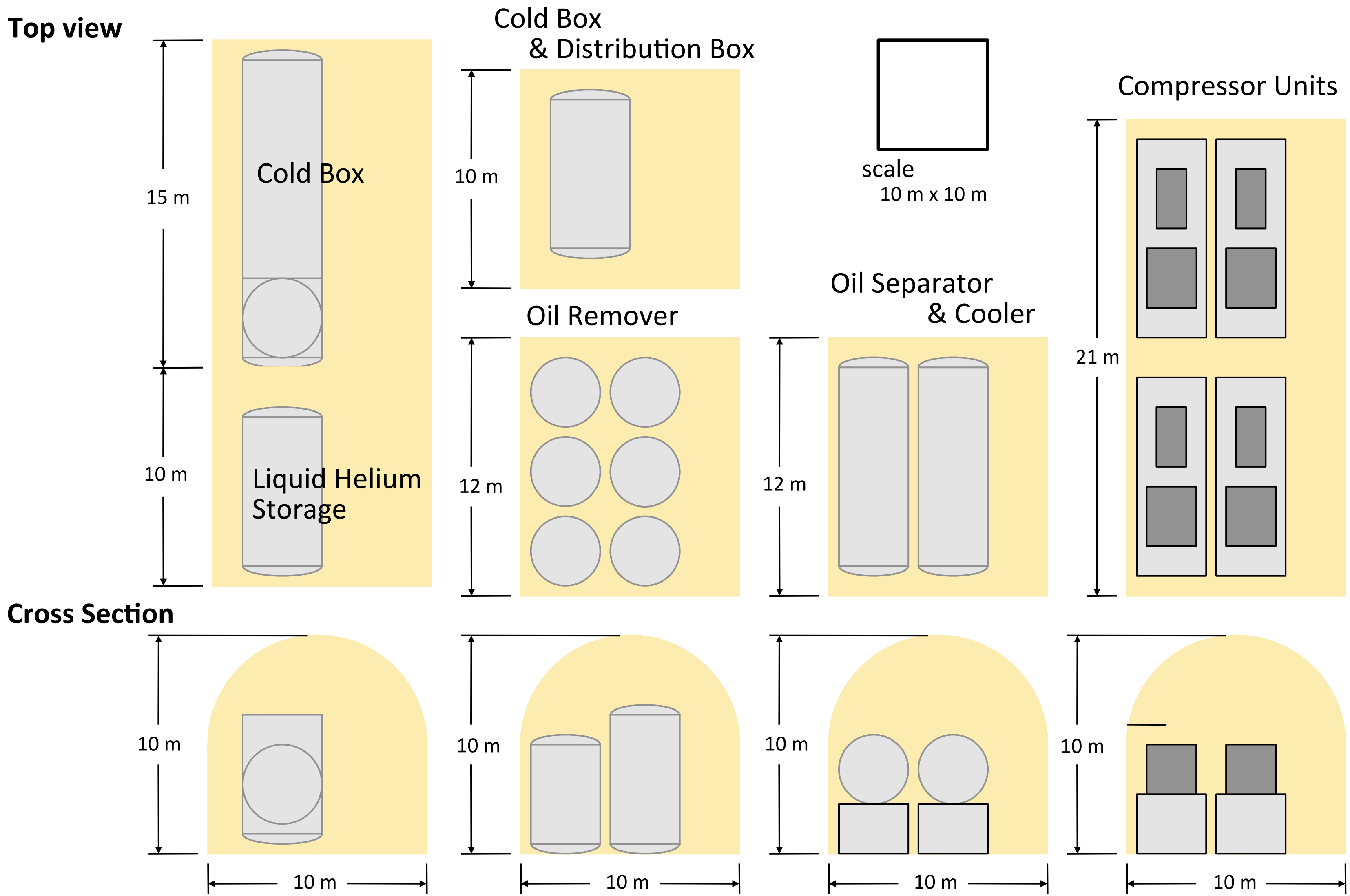
Helium Refrigeration System Components



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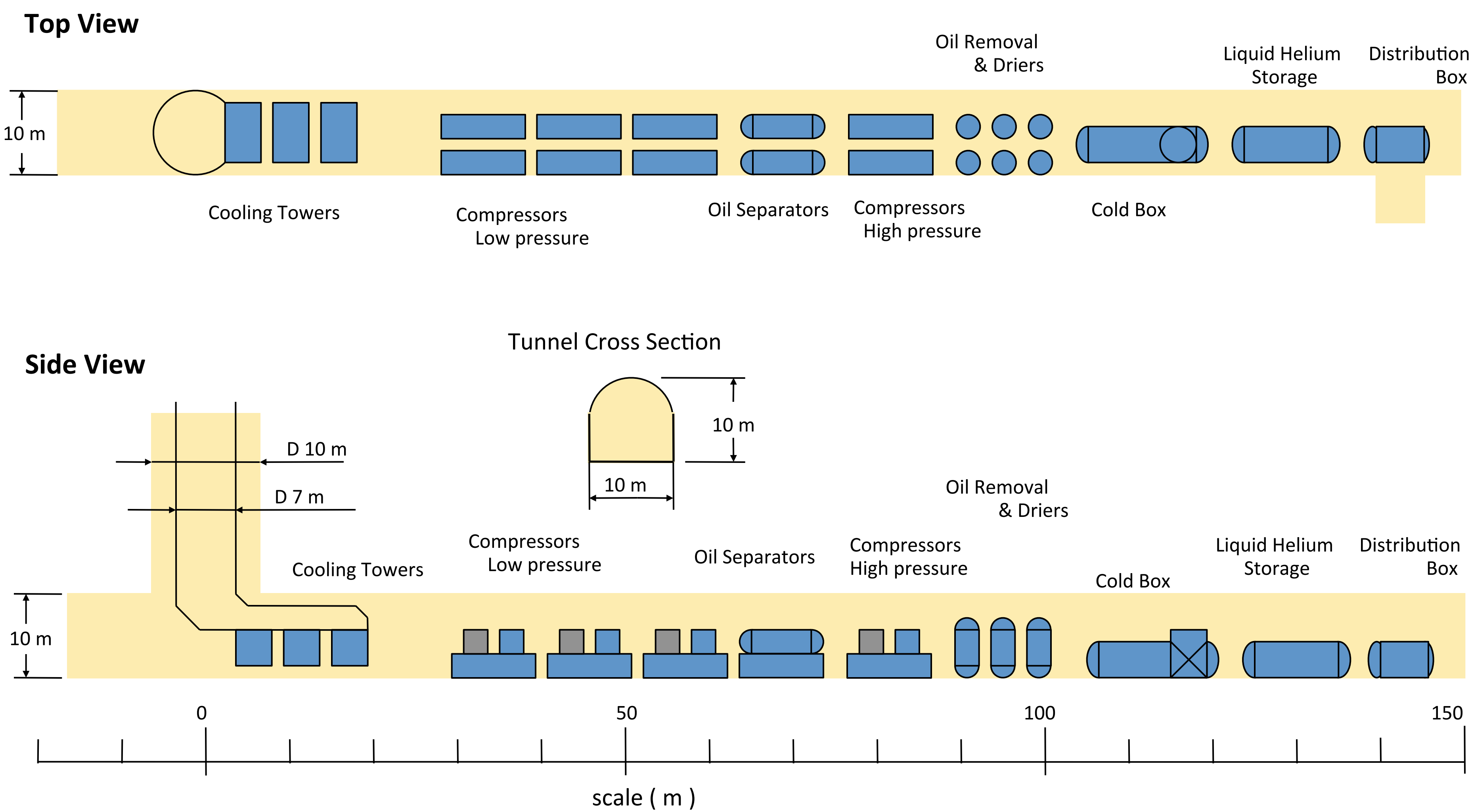
Helium Refrigeration System in Tunnel



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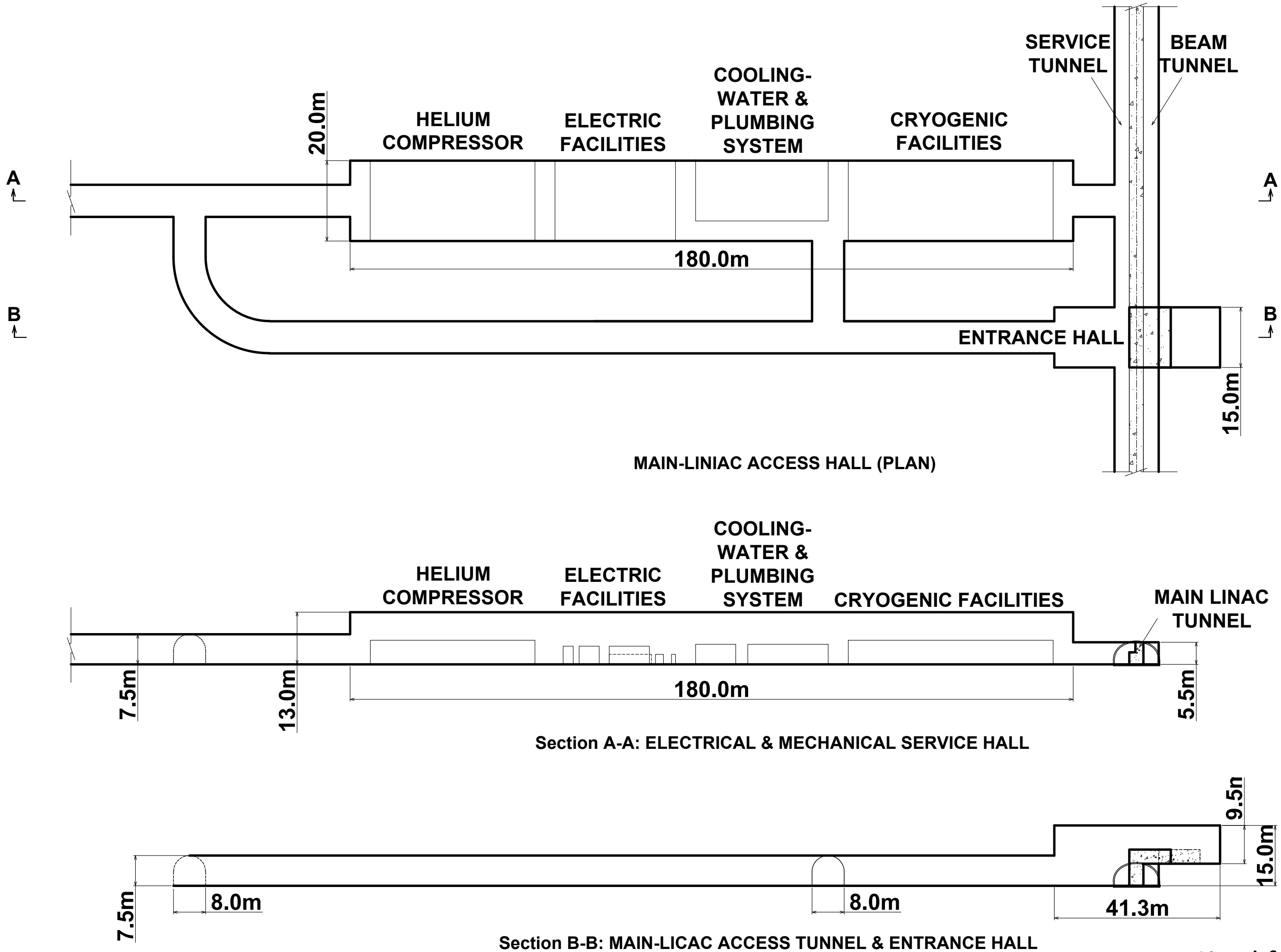
Typical Access Hall (Cryogenic Cavern)



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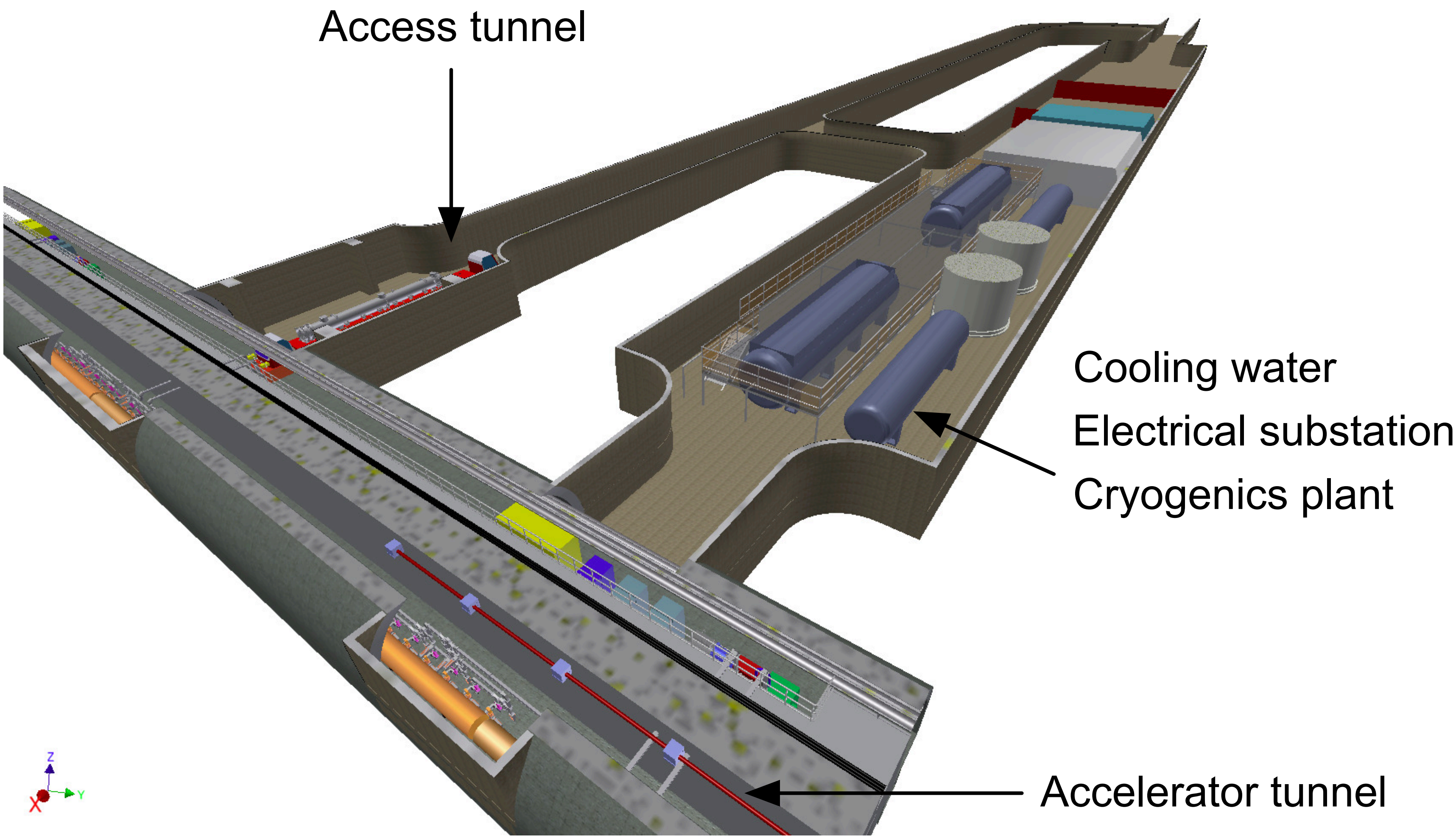
Cryogenic Cavern and Horizontal Access Way



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Summary by Hosoyama at IWLC2010

- Cryogenic caverns will be constructed at the end of the access tunnels at every 5 km intervals of the main tunnel.
- The 4K and 2K cold boxes and distribution box will be installed in cryogenic caverns.
- The compressors will be installed in the far end of cryogenic cavern.
- Large amount of helium inventory will be stored as liquid helium for long shutdown of the cryogenic system.
- The cooling water used at the cryogenic plant will be supplied by cooling towers constructed at entrance of access tunnel. (---> on surface?)
- We need detailed engineering design study of cryogenic system collaboration with industry.
- Extraction of heat from the deep tunnel economically is key issue.
- We need more study including new idea.

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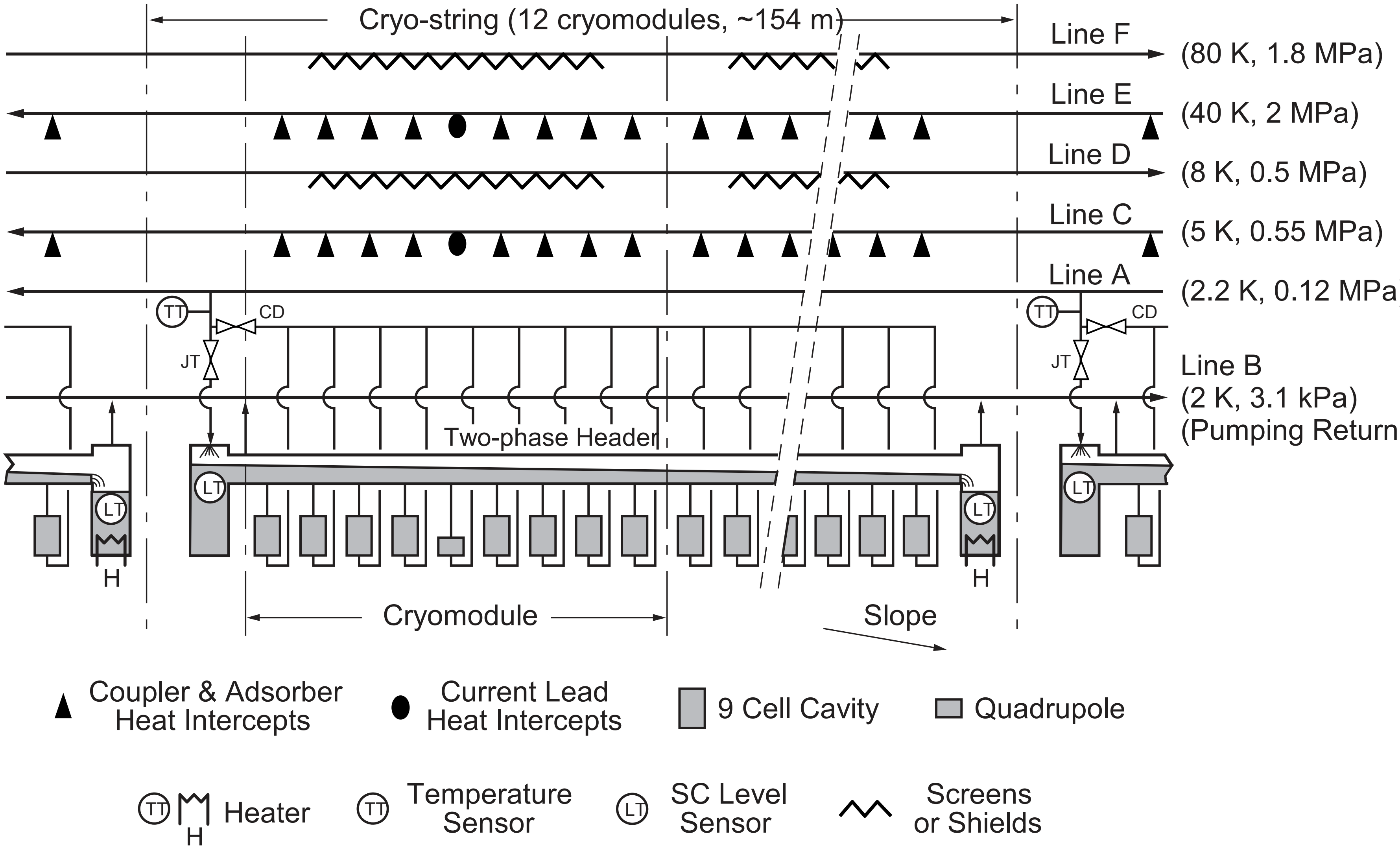
Extra Slides

LINEAR COLLIDER COLLABORATION

Designing the world's next great particle accelerator

Cooling Scheme of Cryo-string



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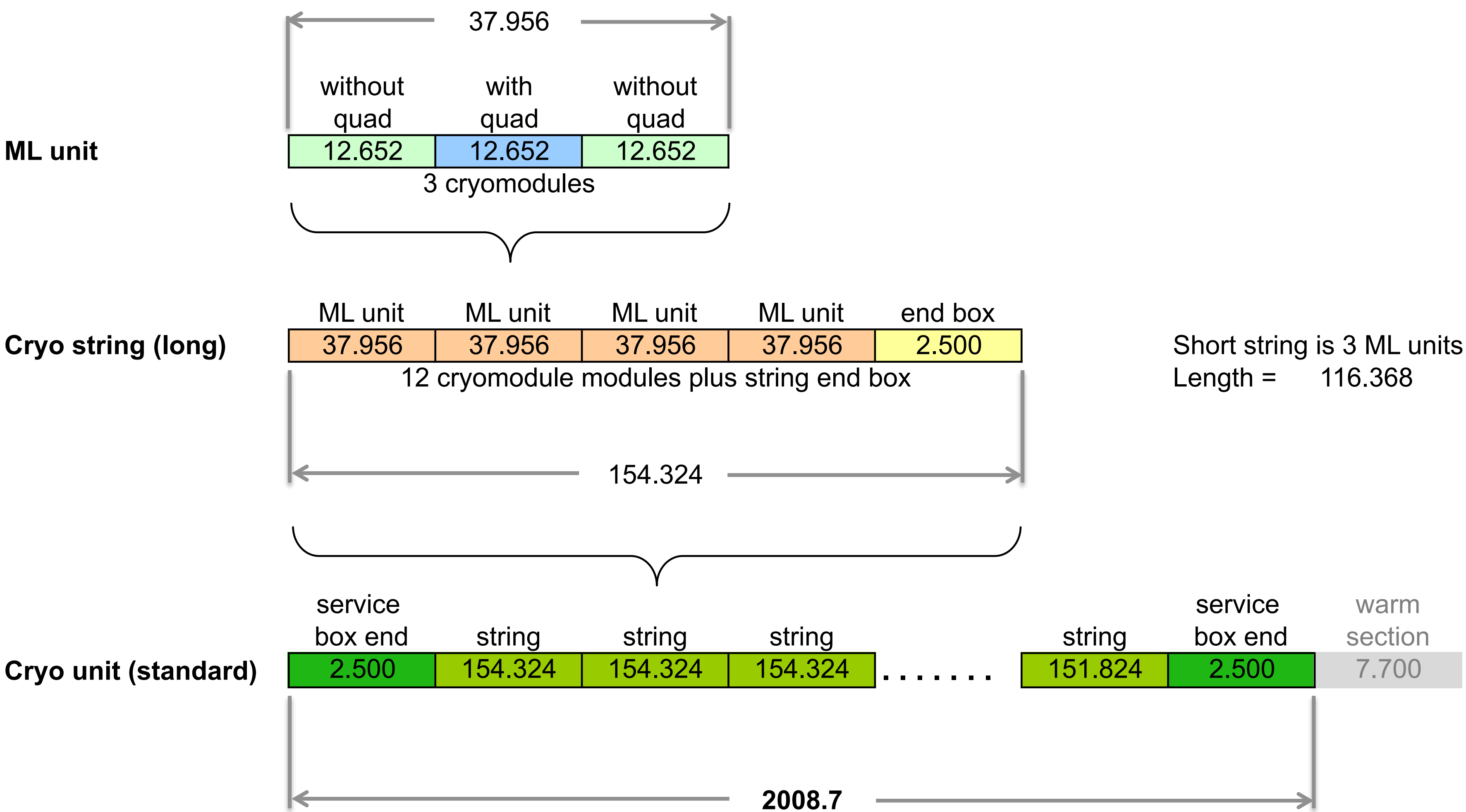
Basic Cryogenic Segmentation in Main Linacs



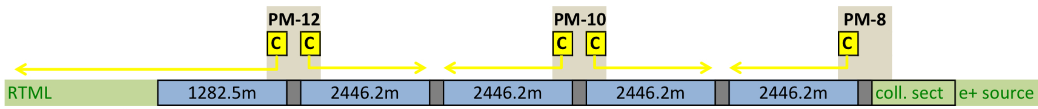
1 cryogenic unit = 13 strings x 4 ML units/string = 52 ML units
with string end boxes plus service boxes

Cited from ILC-TDR

Schematic Layout of Main Linacs

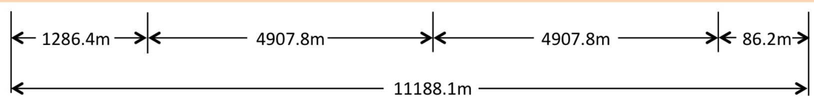
Key:
- warm drift space (7.625 m)
- *L* m cryo unit (with length)
- warm beam line
- Major Vertical shaft (cryo)
- C Cryo plant
- extent / direction of cryo unit

Electron Linac

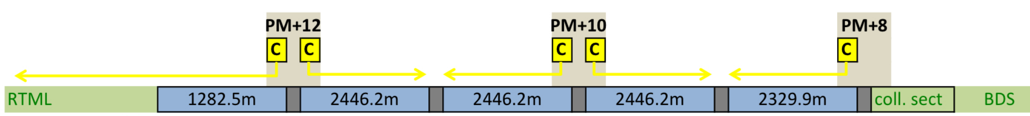


	tot.					
Long strings	0	0	0	0	0	0
Short strings	95	11	21	21	21	21
Cold boxes	90	10	20	20	20	20
ML units	285	33	63	63	63	63
Cryomodules	855	99	189	189	189	189
RF stations	190	22	42	42	42	42

Beam Energy 15 42.9 96.3 149.7 203.0 256.4 GeV

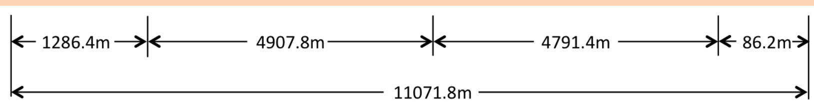


Positron Linac



	tot.					
Long strings	0	0	0	0	0	0
Short strings	94	11	21	21	21	20
Cold boxes	89	10	20	20	20	19
ML units	282	33	63	63	63	60
Cryomodules	846	99	189	189	189	180
RF stations	188	22	42	42	42	40

Beam Energy 15 42.9 96.3 149.7 203.0 253.8 GeV



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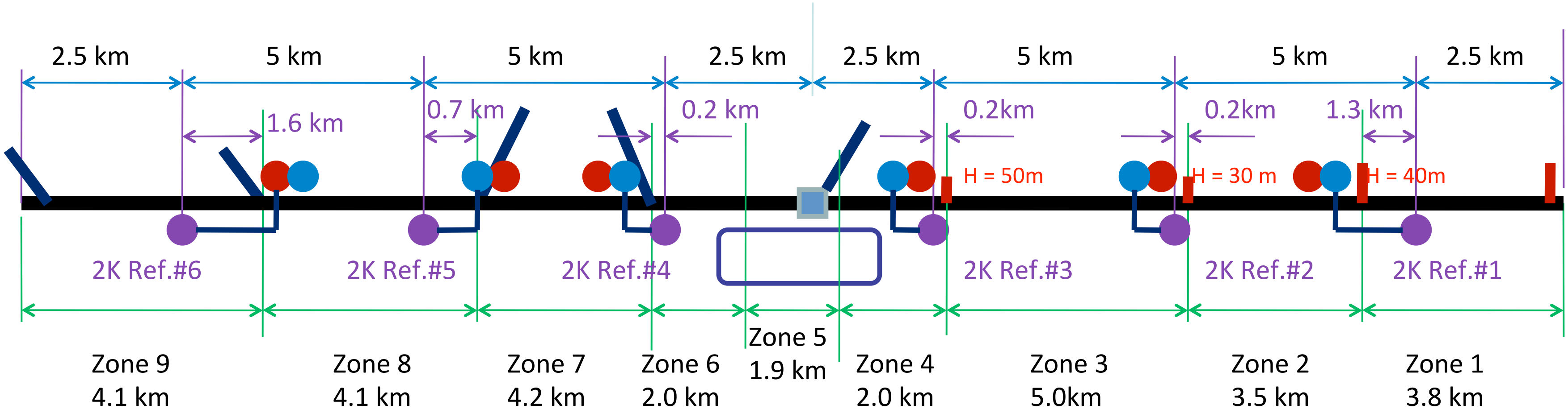
Layout of Cryogenic Plants for Mountain Site A

- 2K cold boxes and distribution boxes will be installed in the cavern in the main tunnel
- 4 K cold boxes & compressor units will be installed at the end of access tunnel



Comments :
1) Long multi-transfer line must be installed in the main tunnel
2) End of access tunnel a large space will be prepared for assembling a TBM. This space can be used for a 4.4 K cold box.
3) Compressor unit will be installed far away from main tunnel in the cavern near by access tunnel.
4) Helium will be recovered as liquid in the Dewar installed near by the 4 K refrigerator cold box.

- 2K Ref. Cold box (+ cold compressor)
- 4.4 K Ref. cold box
- He compressor unit
- Shaft
- Access Tunnel

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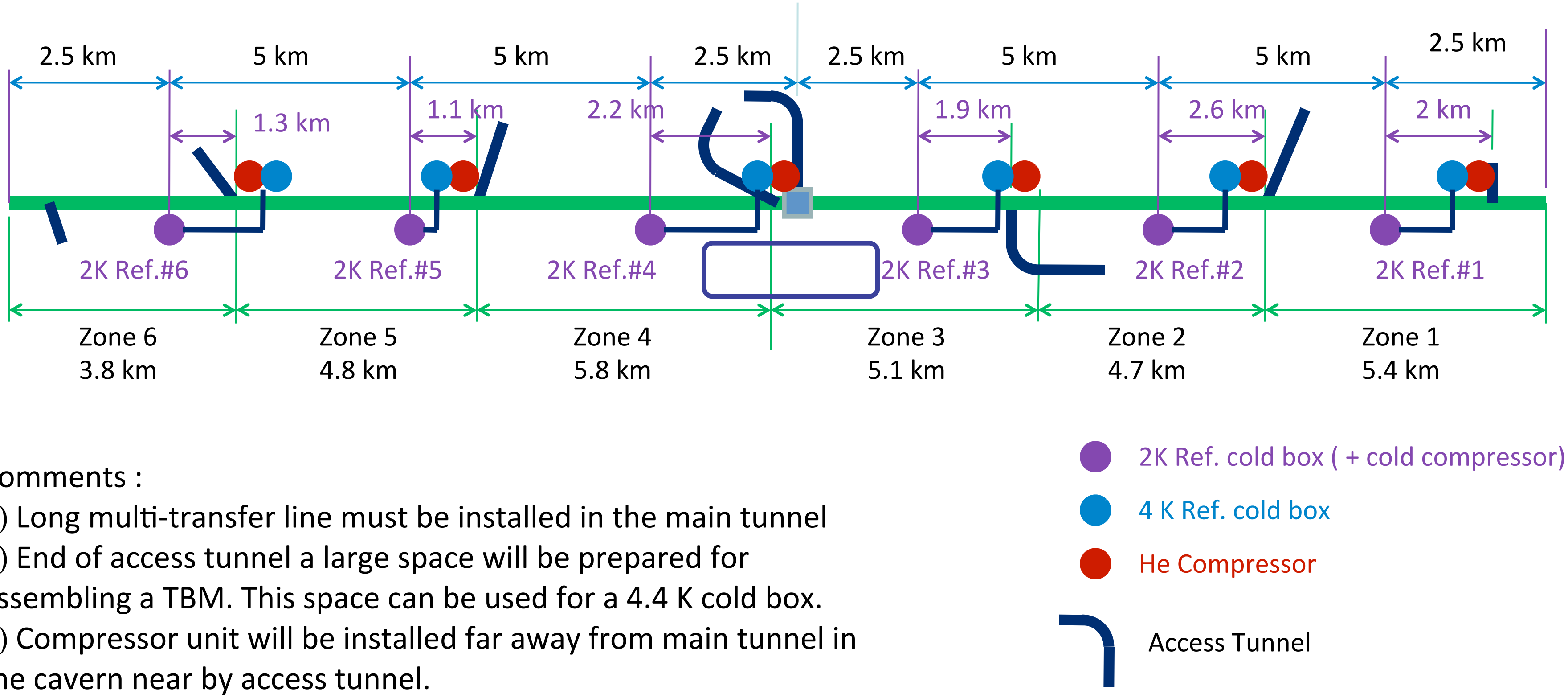
Layout of Cryogenic Plants for Mountain Site B

- 2K cold boxes and distribution boxes will be installed in the cavern in the main tunnel
- 4 K cold boxes & compressor units will be installed at the end of access tunnel



Comments :

1) Long multi-transfer line must be installed in the main tunnel

2) End of access tunnel a large space will be prepared for assembling a TBM. This space can be used for a 4.4 K cold box.

3) Compressor unit will be installed far away from main tunnel in the cavern near by access tunnel.

4) Helium will be recovered as liquid in the Dewar installed near by the 4 K refrigerator cold box.

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Cryogenic Plant Sizes

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

Cited from ILC-TDR

Main Linac AC Power Consumption

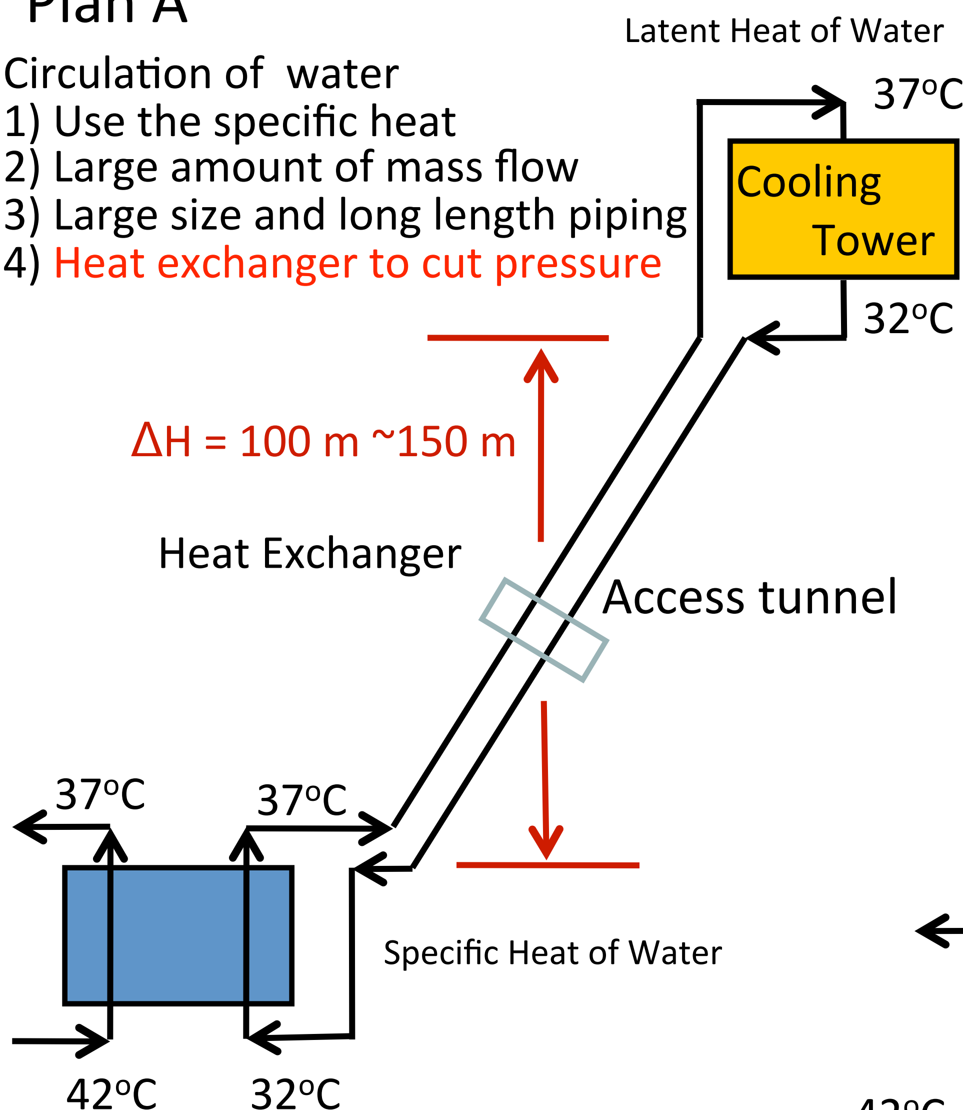
System	Flat Topography AC power (MW)	Mountain Topography AC power (MW)
Modulators	58.1	52.1
Other RF system and controls	5.8	5.5
Conventional facilities	13.3	16.4
Cryogenics	32.0	32.0
Total	109.2	106.1

Cited from ILC-TDR

Extraction of Heat from Tunnel (1)

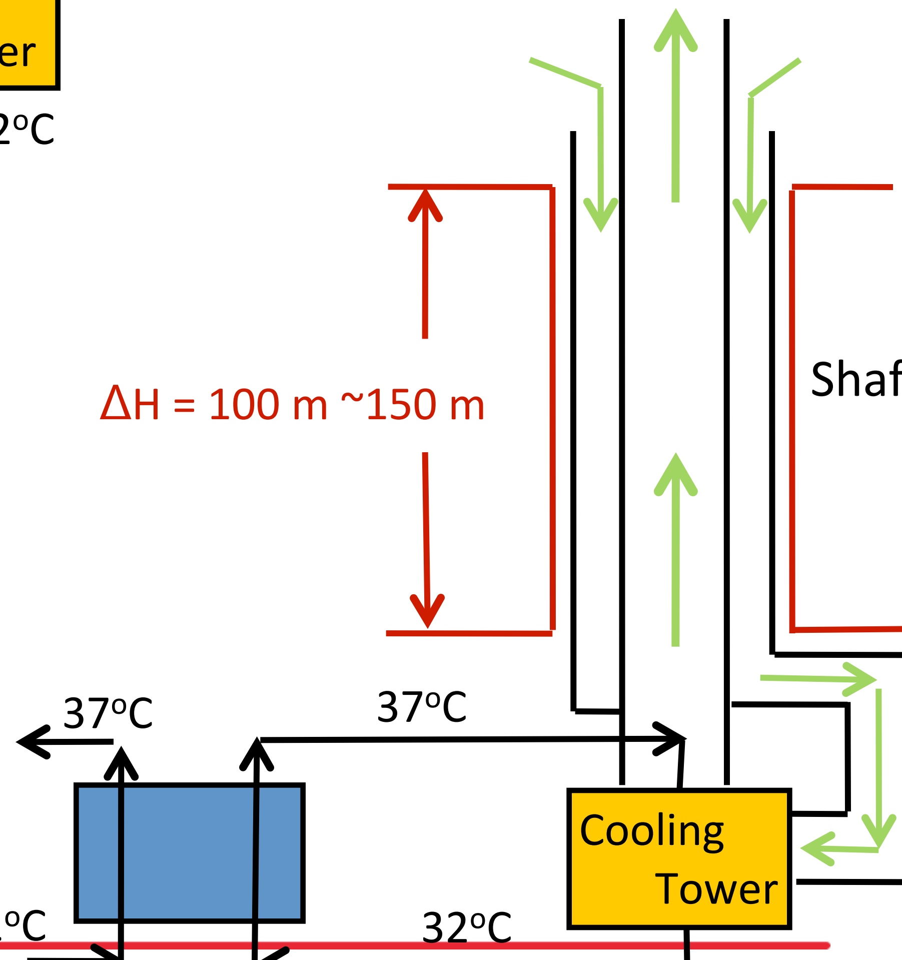
Plan A

Circulation of water
1) Use the specific heat
2) Large amount of mass flow
3) Large size and long length piping
4) Heat exchanger to cut pressure



Plan A'

Underground Cooling Tower
1) Eliminate the heat exchanger
2) Need large diameter shaft

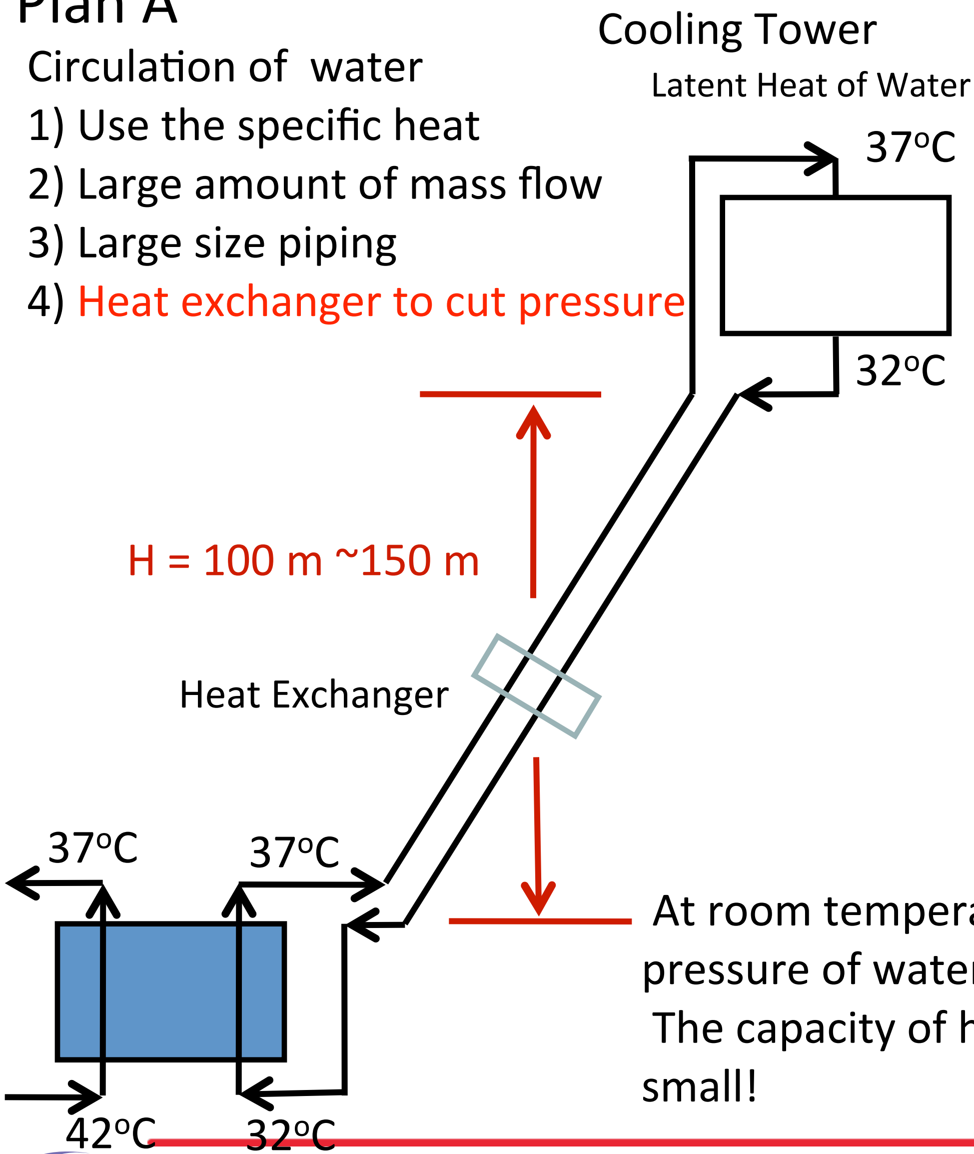


Extraction of Heat from Tunnel (2)

Plan A

Circulation of water

1) Use the specific heat
2) Large amount of mass flow
3) Large size piping
4) Heat exchanger to cut pressure



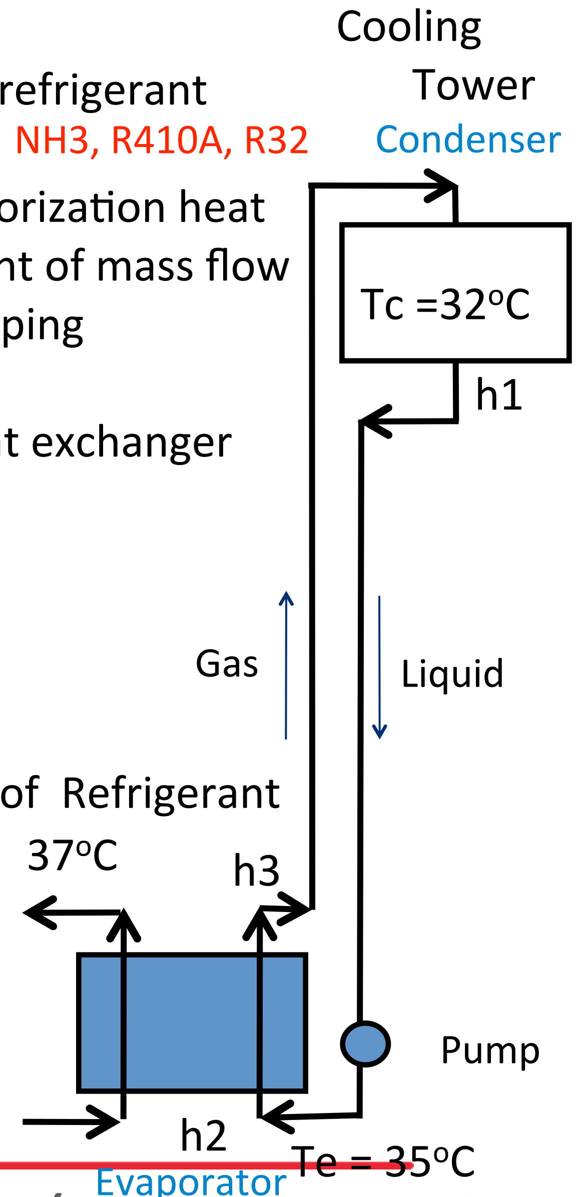
At room temperature, the vapor pressure of water is very low.
The capacity of heat flow is very small!

Plan B

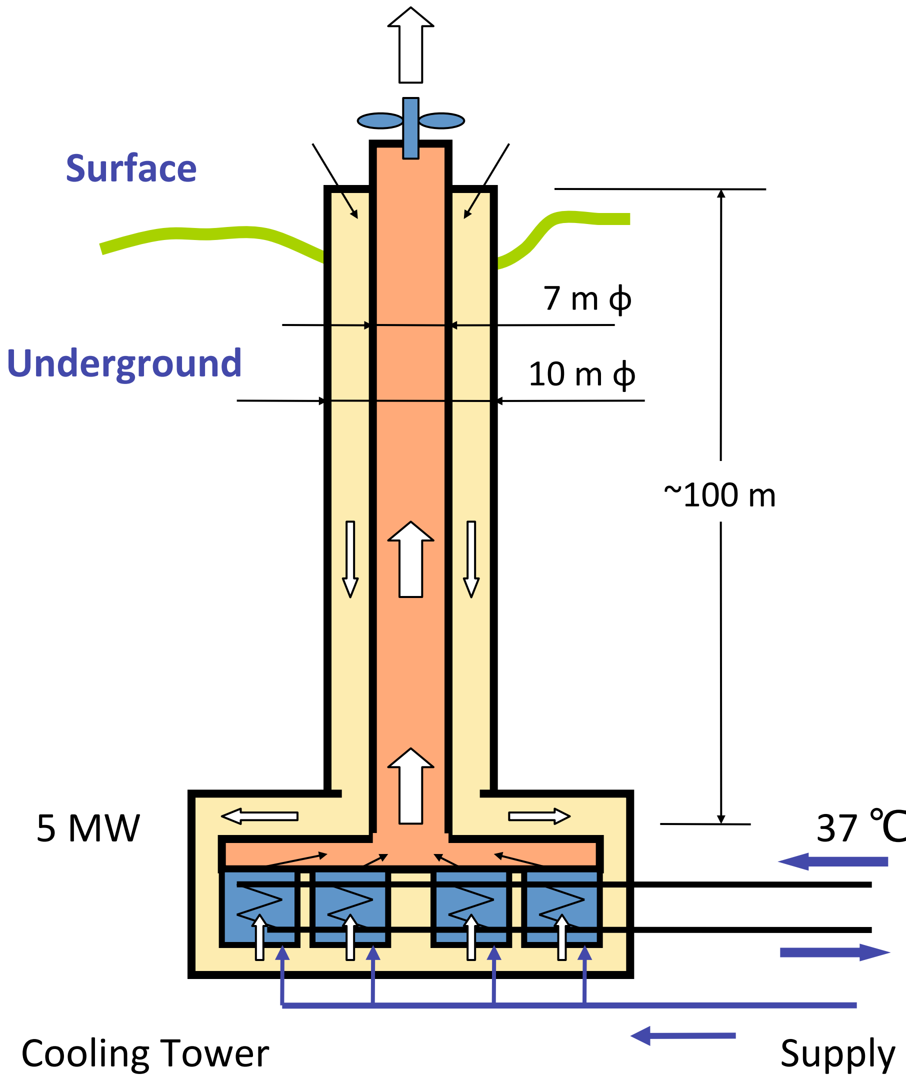
Circulation of refrigerant

NH3, R410A, R32

1) Use the vaporization heat
2) Small amount of mass flow
3) Small size piping
4) Eliminate the heat exchanger



Underground Cooling Tower



1 L/s = 539 kcal/s = 2253 kW
1 MJ = 0.44 L/s = 1.6 m^3/h

Cooling Tower

Fan ϕ 2 m ~ 3 m^2 0.5 MW

5 MW 30 m^2 60 m^2 ~ ϕ 9 m

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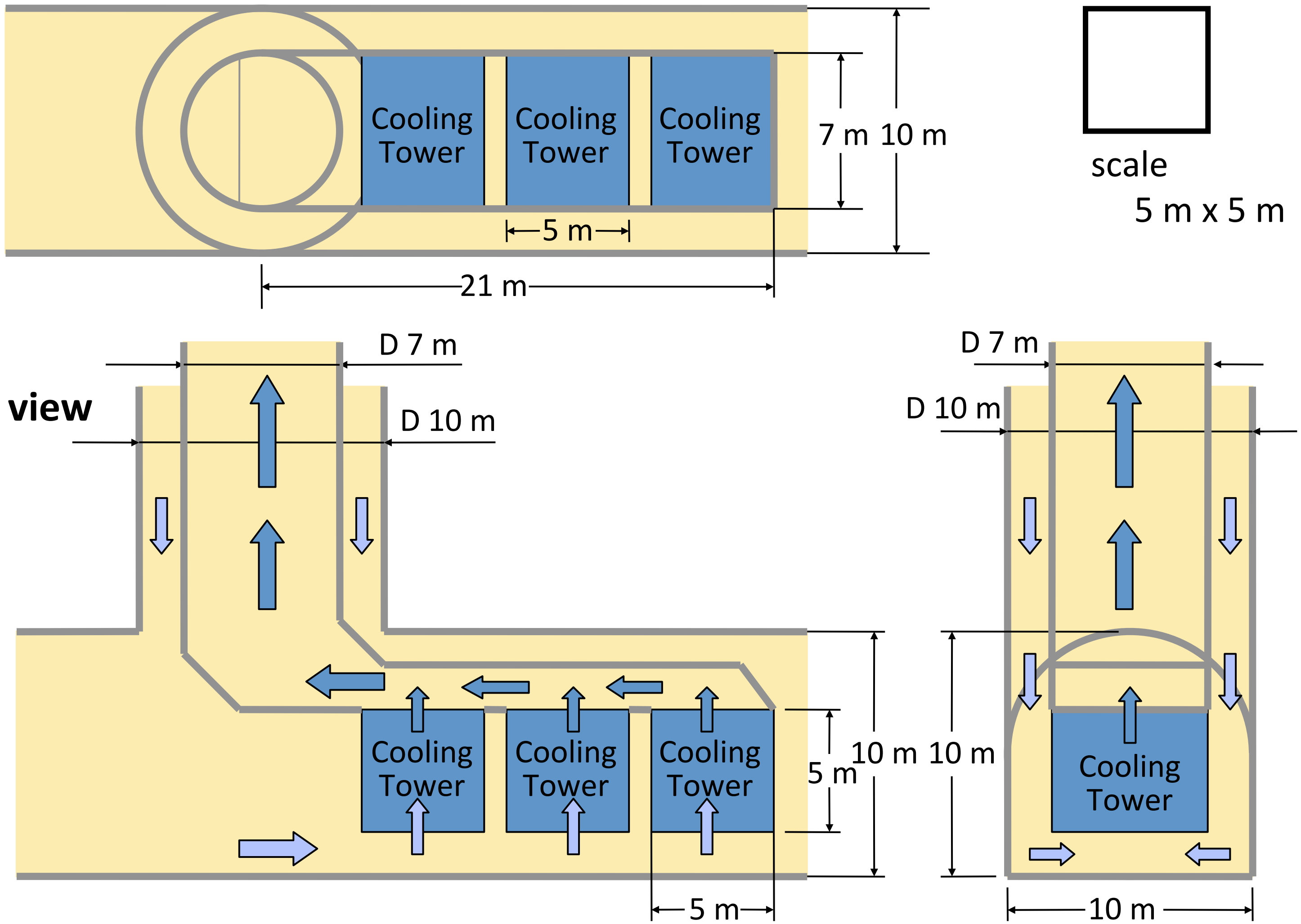
Underground Cooing Towers

Top view

Side view



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Heat Transfer Capacity of Refrigerants

	WATER	AIR	NH3		R410A		R32	
			Liquid	Gas	Liquid	Gas	Liquid	Gas
Te ℃	37	37	35	35	35	35	35	35
Pe kPaA	---	---	1350.8		2139.9			
Tc ℃	32	32	32	32	32	32	32	32
Pe kPaA	---	---	1238.2		1975.6			
Density t/m3	1	0.0012	0.587	0.0105	1.008	0.0883	0.912	0.0652
Specific Heat Mcal/t•℃	1	0.24	---	---	---	---	---	---
ΔT ℃	5	5	---	---	---	---	---	---
Latent Heat Mcal/t	---	---	268		40.5		59.0	
Velocity m/s	1	5	1	5	1	5	1	5
Cooling Power Mcal/m2•h	5	0.0072	157.3	14.1	40.8	17.9	53.8	19.2

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Motor Power for Circulation of Refrigerants

30 MW Heat Load Case

	WATER	AIR	NH3		R410A		R32	
			Liquid	Gas	Liquid	Gas	Liquid	Gas
Mass Flow Rate t/h	5160	21500	96.3		637.0		437.3	
Velocity m/s	1.0	5.0	1.0	5.0	1.0	5.0	1.0	5.0
Pipe Size m	1.35	35.60	0.24	0.81	0.47	0.71	0.41	0.69
⊿P(@100m) k Pa	5		1.3	1.3	0.2	0.2		
Pipe Size m	1.00	35.60	0.24	0.81	0.47	0.71	0.41	0.69
Velocity m/s	1.82	5.00	1.00	5.00	1.00	5.00	1.00	5.00
⊿P(@100m) k Pa	16.7		1.3	1.3	0.2	0.2		
Pipe Length m	4000	2000	100	100	100	100	500	500
⊿P k Pa	666.1	0	1.3	1.3	0.2	0.2	0	0
⊿H m	0 *	0	100	100	100	100	100	100
Water Head k Pa	0 *	0	587	10.5	1008	88.3	912	65.2
⊿P at H.X. k Pa	100	0		50		50		
Total ⊿P k Pa	766	0	588.3	61.8	1008.2	138.5	912	65.2
Pe-Pc k Pa			112.6		164.3			
Pump Efficency %	60%							
Motor Power k W	1318		No Need	No Need	No Need	No Need		
Moter Power / Cooling Power	4.4%		0.0%		0.0%			

Ideal case: larger pipe size for water

Water pipe size: 1m in dia.

Note:
In the case of water ;
head of flow and return cancelled

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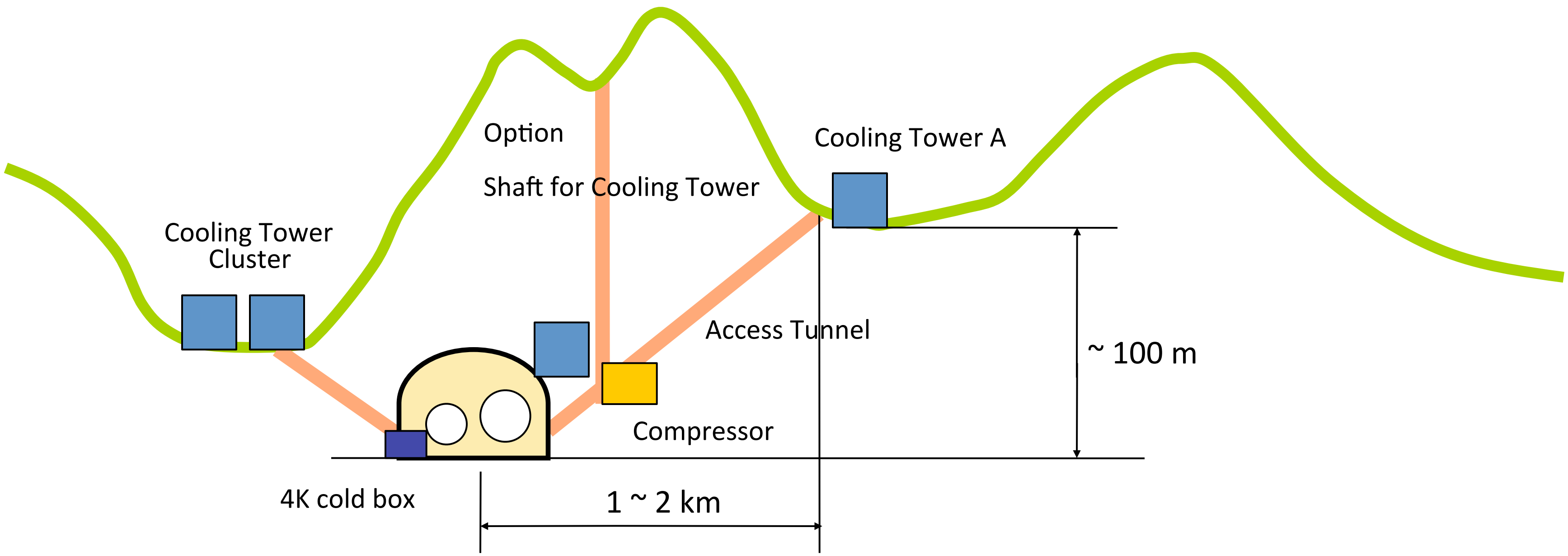
Conceptual Design of Water Cooling System



- Cooling tower at the entrance of access tunnel can support cooling of underground 2 cryogenic plants.
- Cooling tower cluster can support cooling of ~ 8km long distributed heat load. The cooling water circulate in 900 mm in diameter pipe.
- By installation of the cooling tower in the tunnel, we can eliminate heat exchanger which need to cut the head pressure. But we need large bore shaft.
- By using the “thermo-siphon” of refrigerant we can reduce the pipe size.

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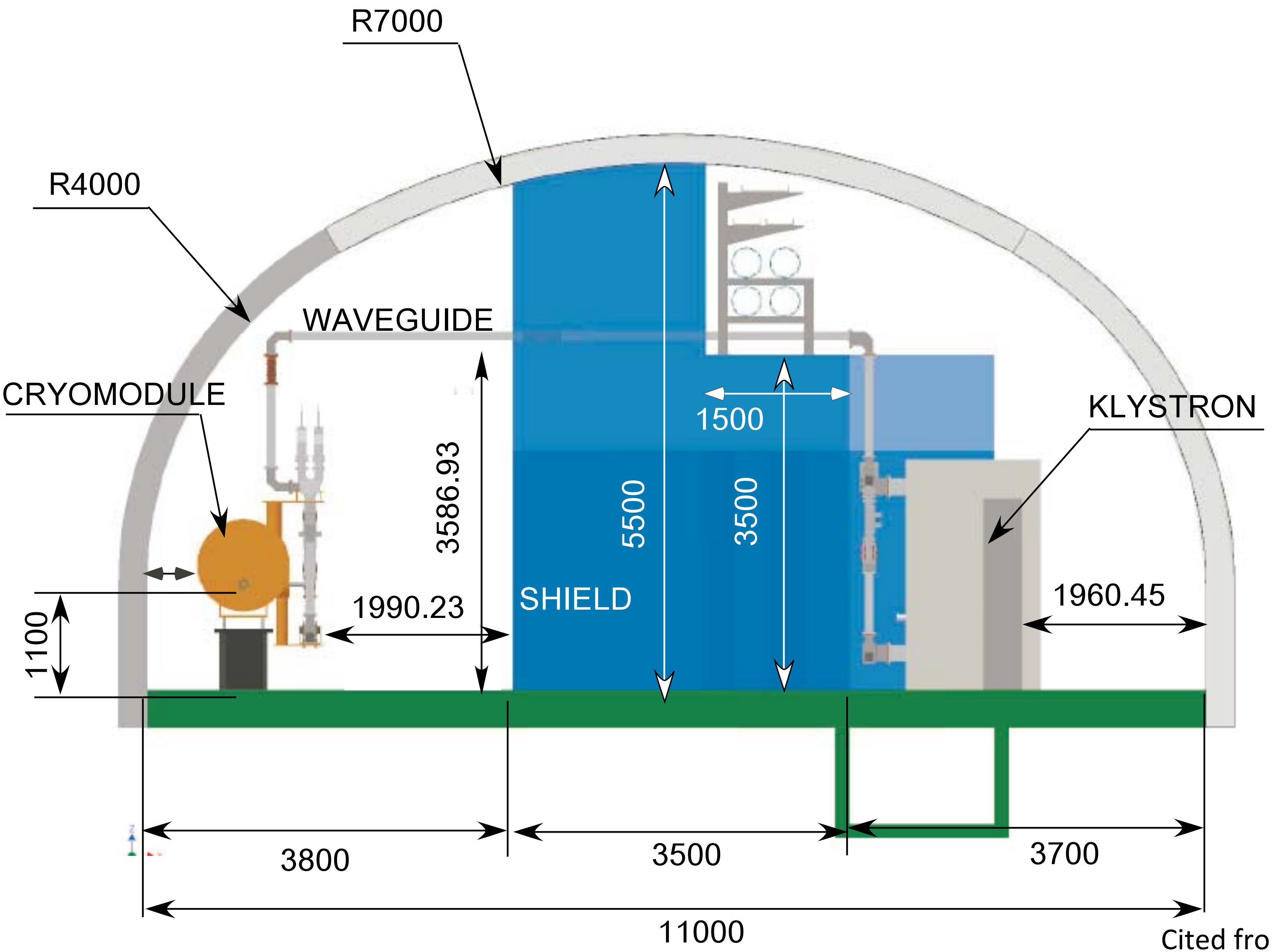
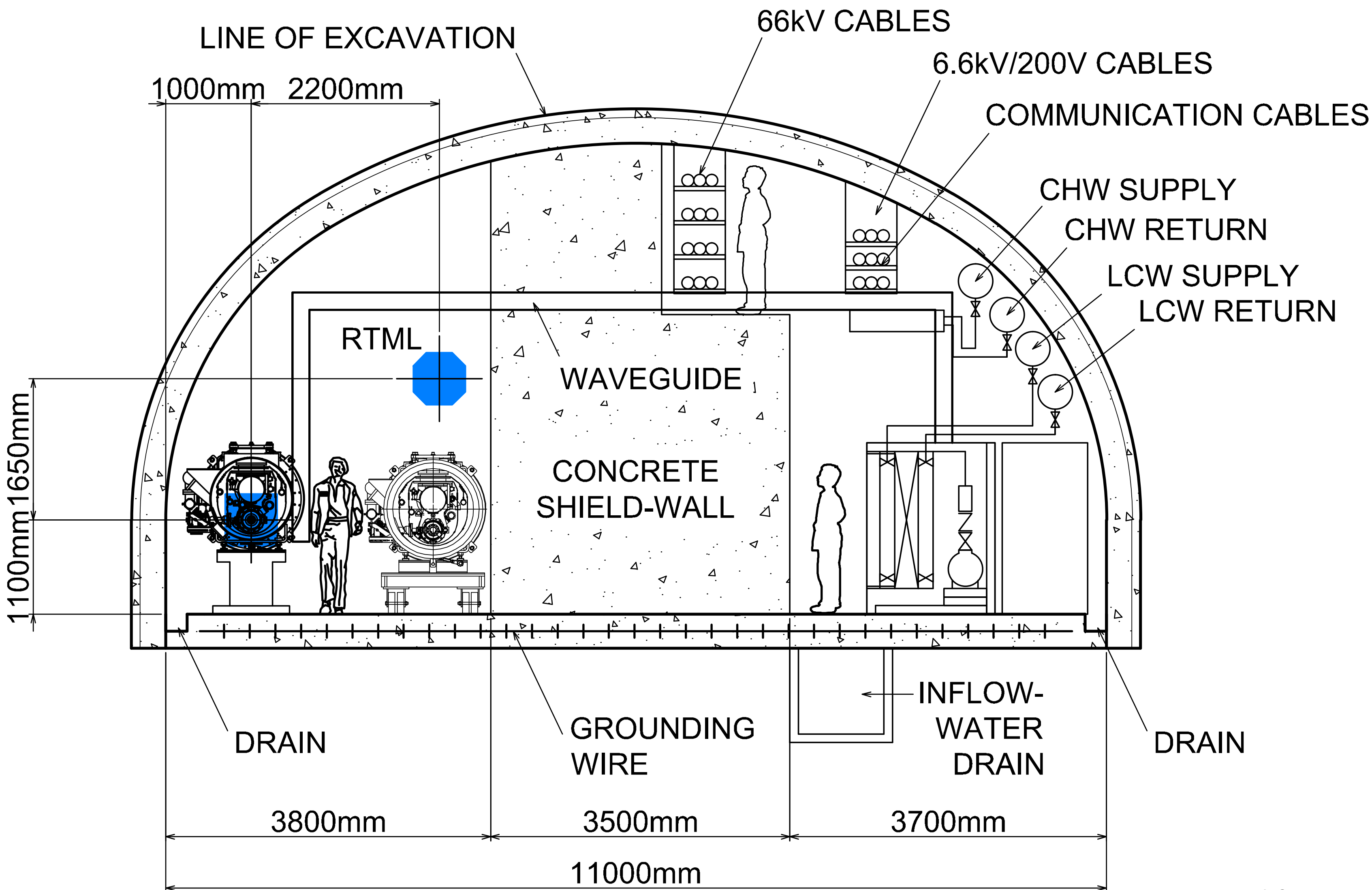
Cross Section of Main Linac Tunnel "Kamaboko"



Cited from ILC-TDR

Equipment Layout in Main Linac Tunnel



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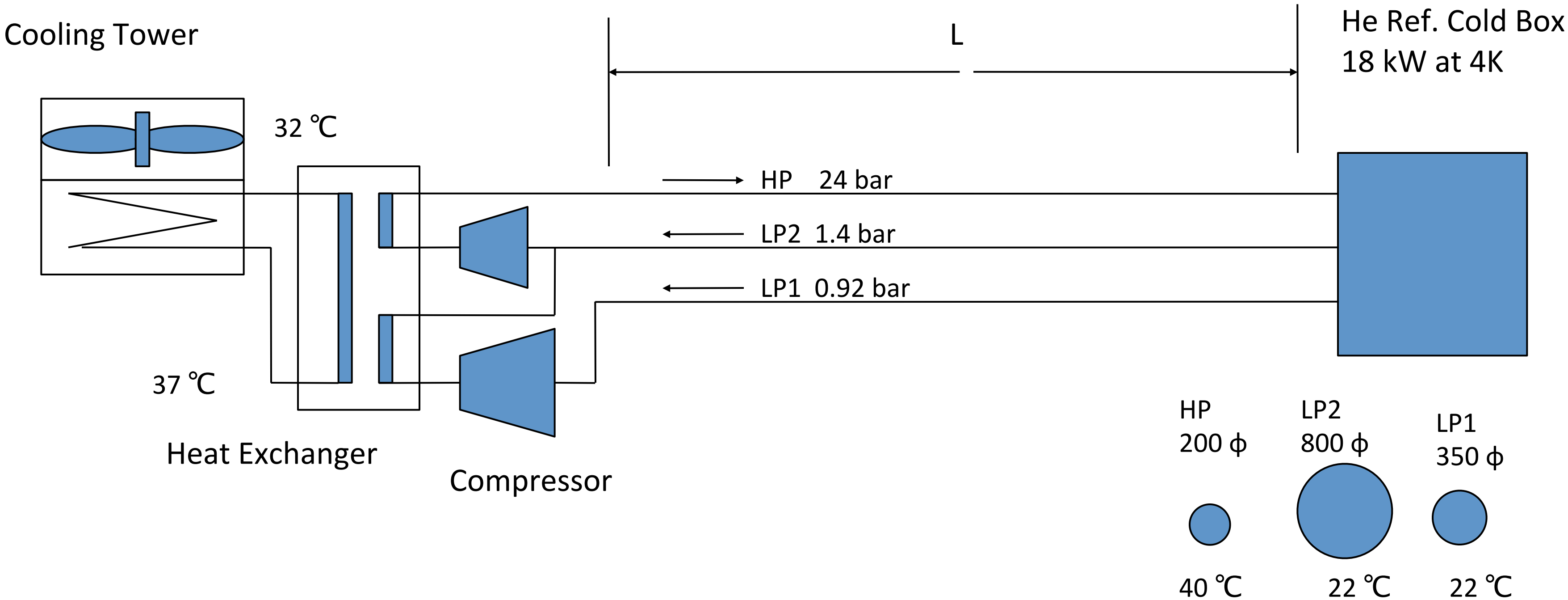
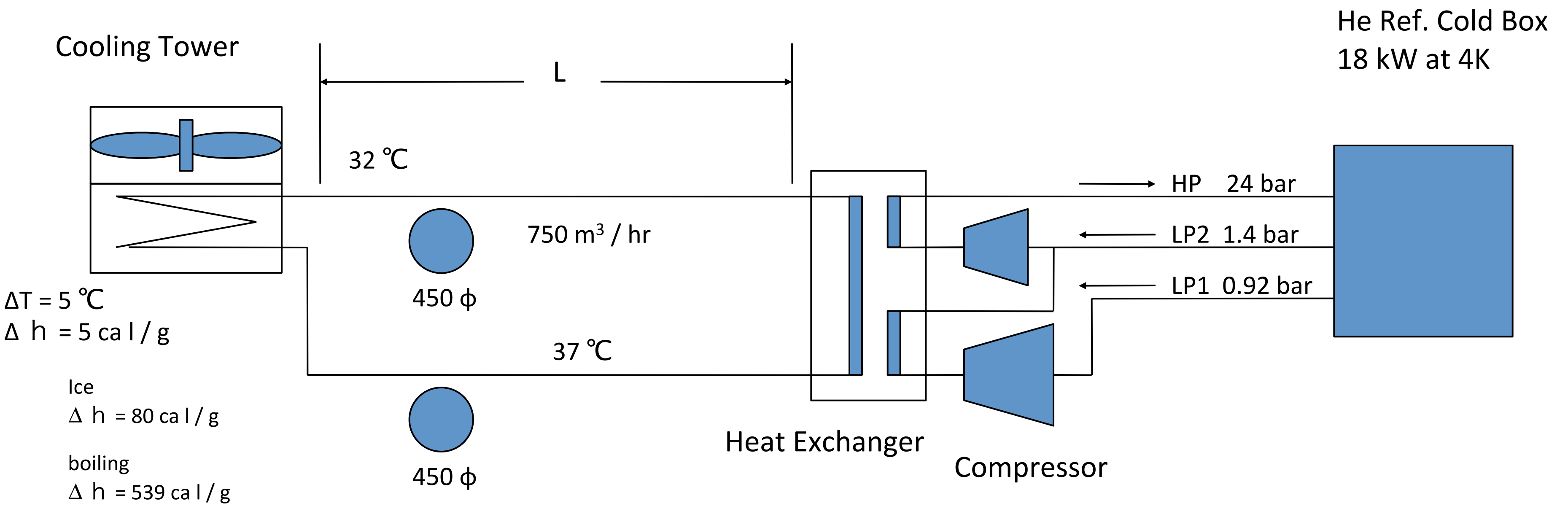
Pressure Drop and Power Loss in Helium Pipes



	ΔHP	ΔLP2	ΔLP1 (bar)	Power
L = 10 m	0.007	0.000	0.000	4.3 MW
L = 1000 m	0.695	0.008	0.017	+1.2 %
L = 2000 m	1.389	0.017	0.034	+2.4 %

Hosoyama, 2010

Pressure Drop and Power Loss in Water Pipes



	ΔP pipe	ΔP total (bar)	Power	
L = 10 m	0.000	3.02	125.0 kW	6.7 %
L = 1000 m	1.55	4.57	187.1 kW	6.9 %
L = 2000 m	3.04	6.06	245.3 kW	7.1 %

Hosoyama, 2010