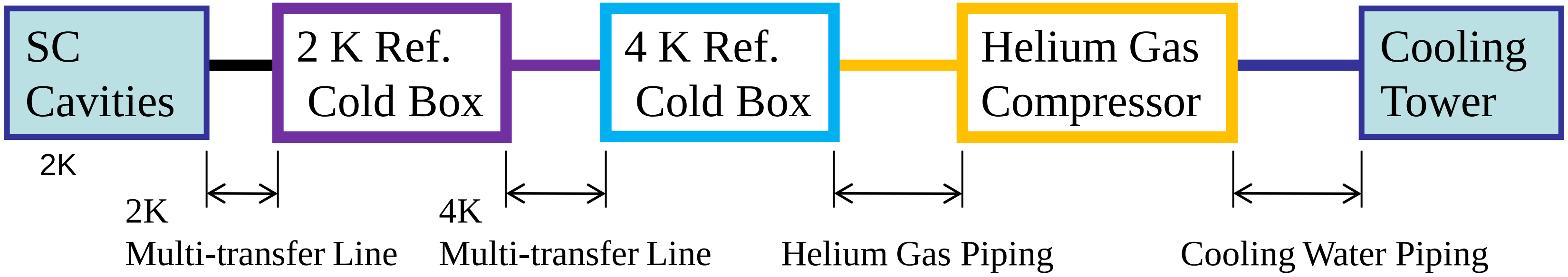
Cryogenic cavern in Asian site

- Conceptual design of the cryogenic system
- Layout of the cryogenic plant for site A & B
- New layout of the cryogenic system
- Storage of helium inventory
- Cooling water for cryogenic system
- Summary & Future Plan

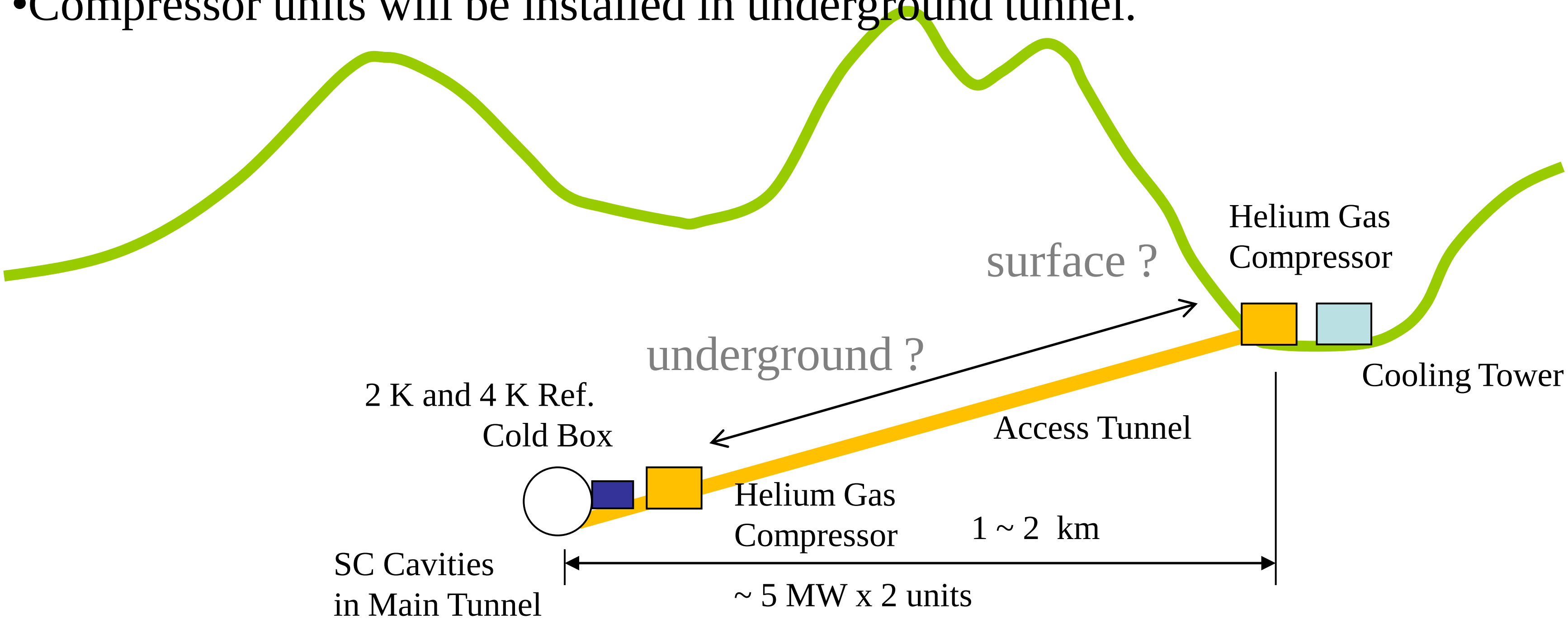
KEK
K. Hosoyama

Conceptual Design of Cryogenic System 1

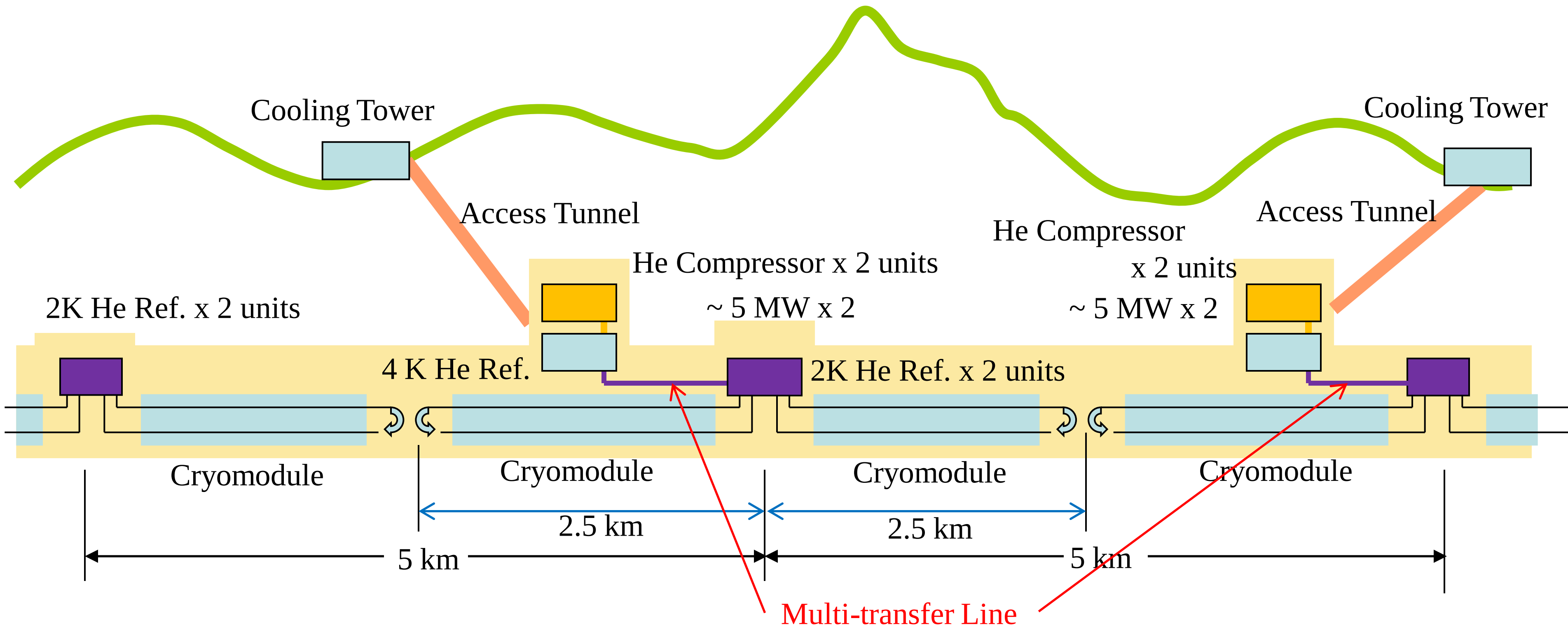


There are many option of layout of main components:

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



Conceptual Design of Cryogenic System 2

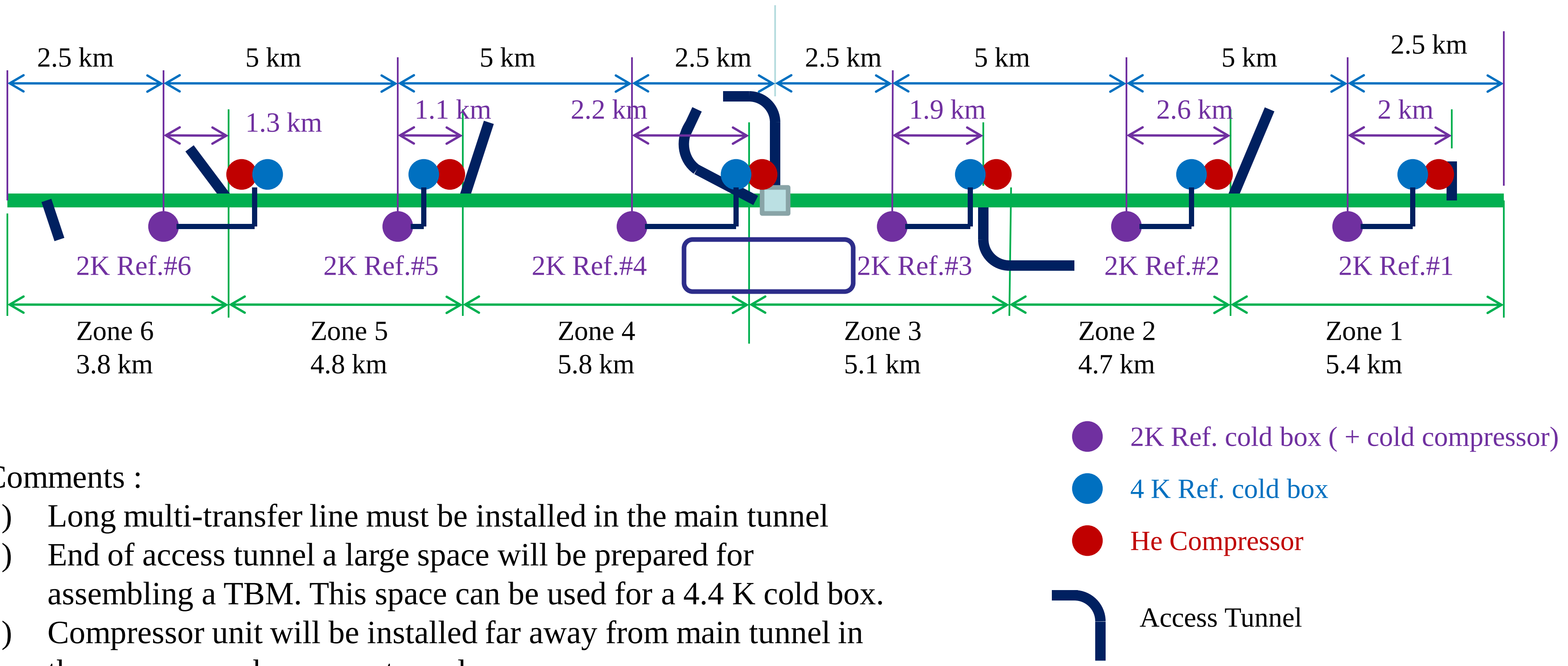


- 4K cold boxes will be installed in the large caverns at the end of access.
- Two 2K cold boxes must be installed in the caverns at 5 km intervals and each 2K cold box supports cooling of ~2.5 km long cryogenic unit.

- 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.

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

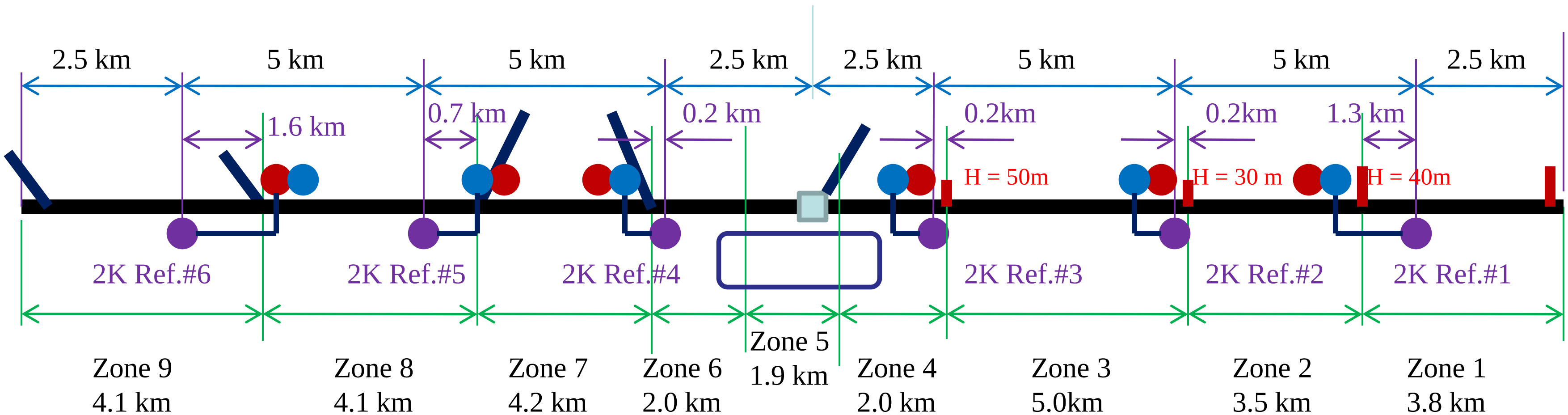


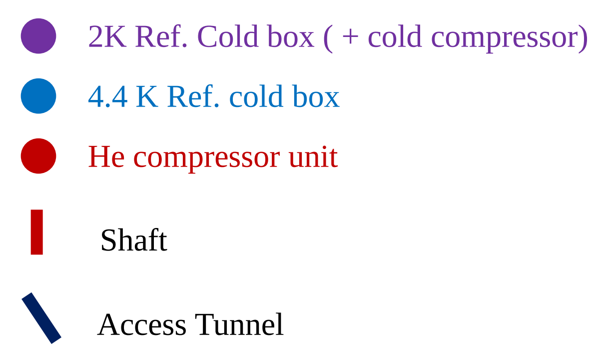
Comments :

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.

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





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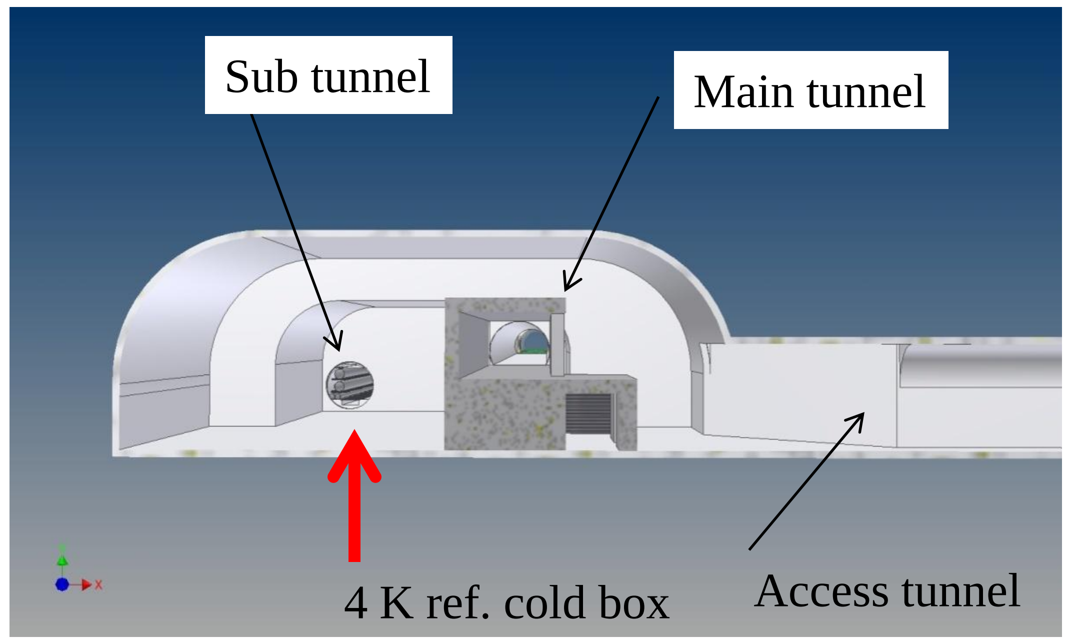
Cryogenic Cavern (old version)

18kW Helium ref. cold box / CERN LHC

- The 4K ref. cold box can be installed in cavern prepared for assembling TBM
- The size of the cold box will be limited by transportation on road from factory to the site

Transportation of the cold box



Cavern at the end of access tunnel: used for assembling TBM for the tunnels

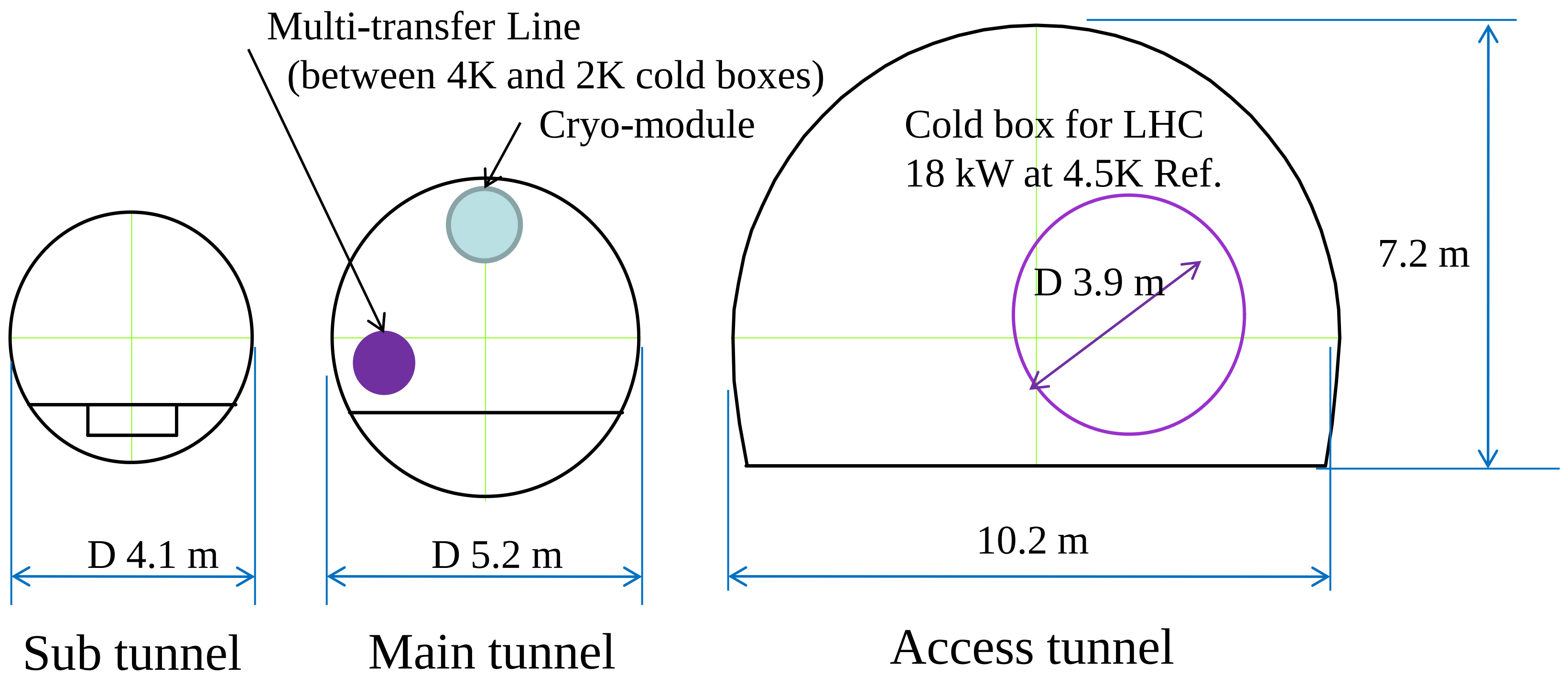
Installation of Main Cryogenic Components

- 4K cold box will be carried through the access tunnel to the cavern at the end of access tunnel.

  -- Enough cross section for transportation of 4K cold box and compressor unit!

Problems:

- 2K cold box must be carried in and out through the main tunnel.
- 2K caverns must be constructed for installation of 2K and distribution boxes.
- Multi-transfer line must be installed in the crowded main tunnel.



New Layout of Cryogenic Plant

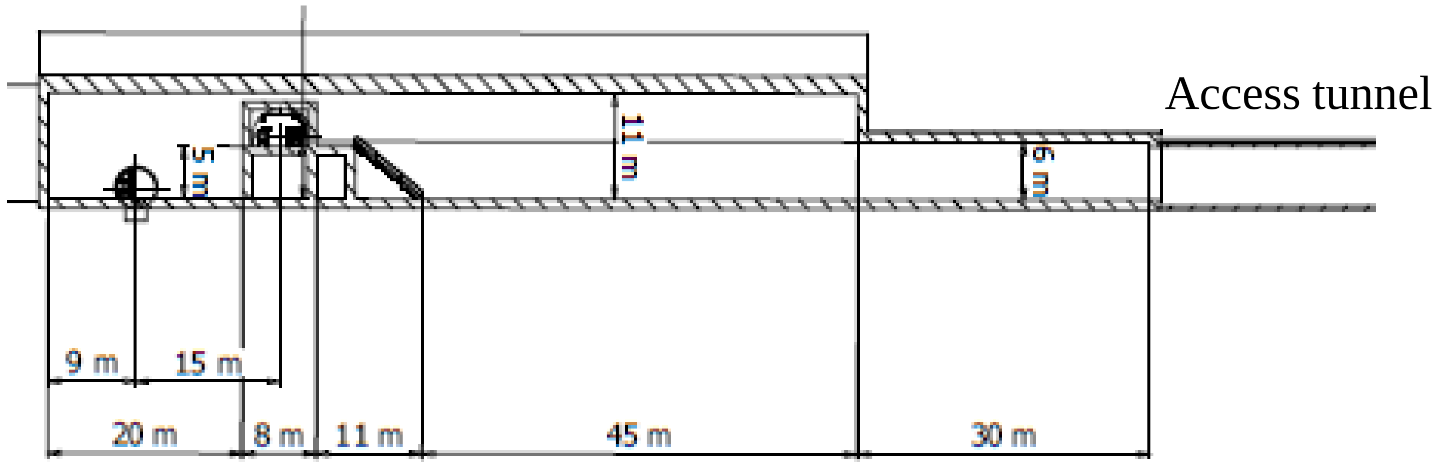
- To solve following problems:
  a) Installation of 2K cold through main tunnel
  b) Need the 2K cryogenic cavern and the long multi-transfer line.

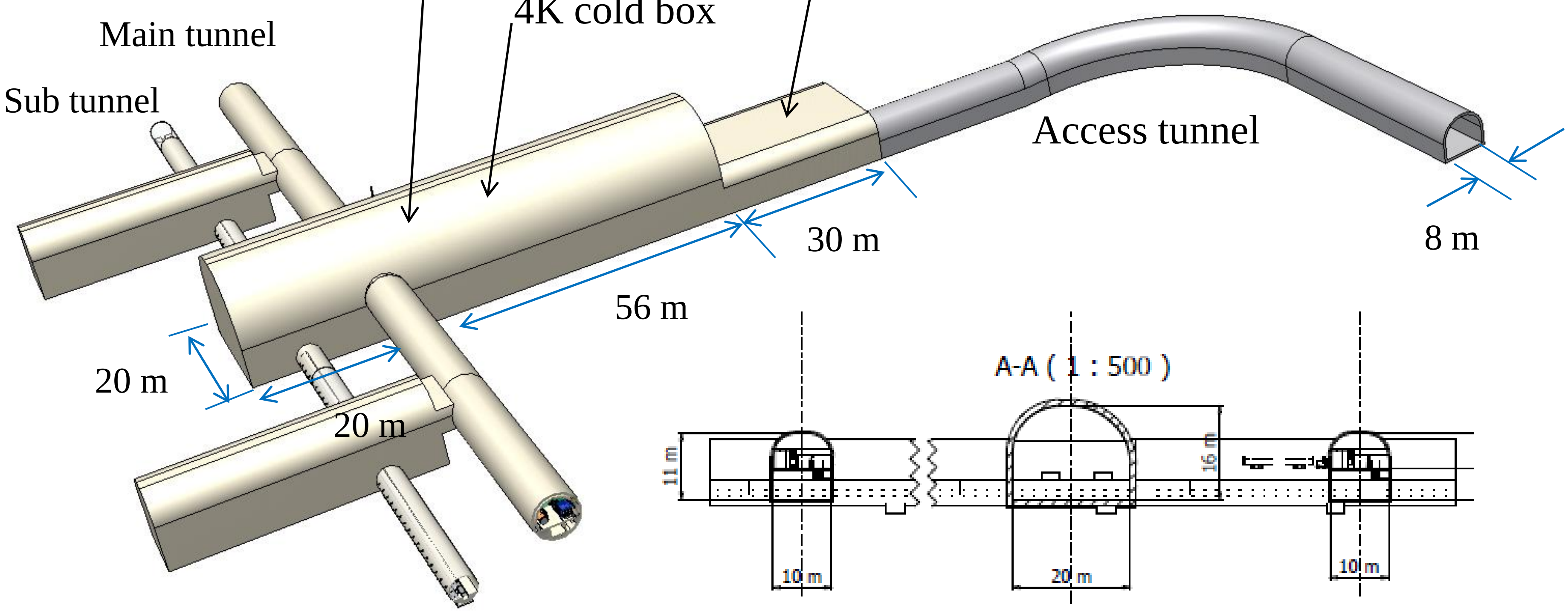
--- We decide to change the route of access tunnels to reach to the 2K cold boxes!

New access tunnel plan:

- Cryogenic caverns will be constructed at the end of the access tunnels at every 5 km intervals in the tunnel.
- Main components of two cryogenic plants:
  compressor units, 4K refrigerator cold boxes, 2K cold boxes, distribution boxes, and multi-channel transfer line, will be installed in the cryogenic cavern.

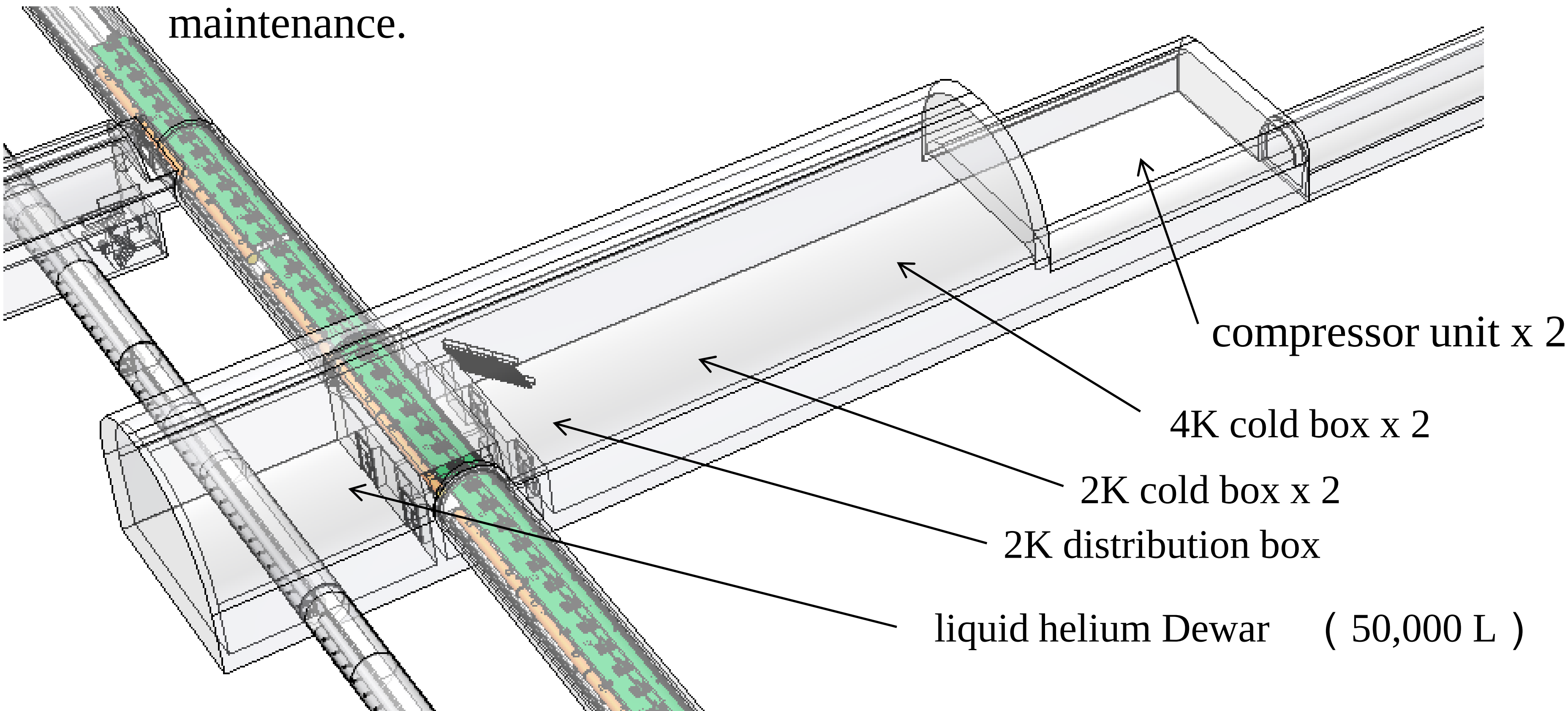
Concept of New Cryogenic Cavern





Detailed Structure of Cryogenic Cavern

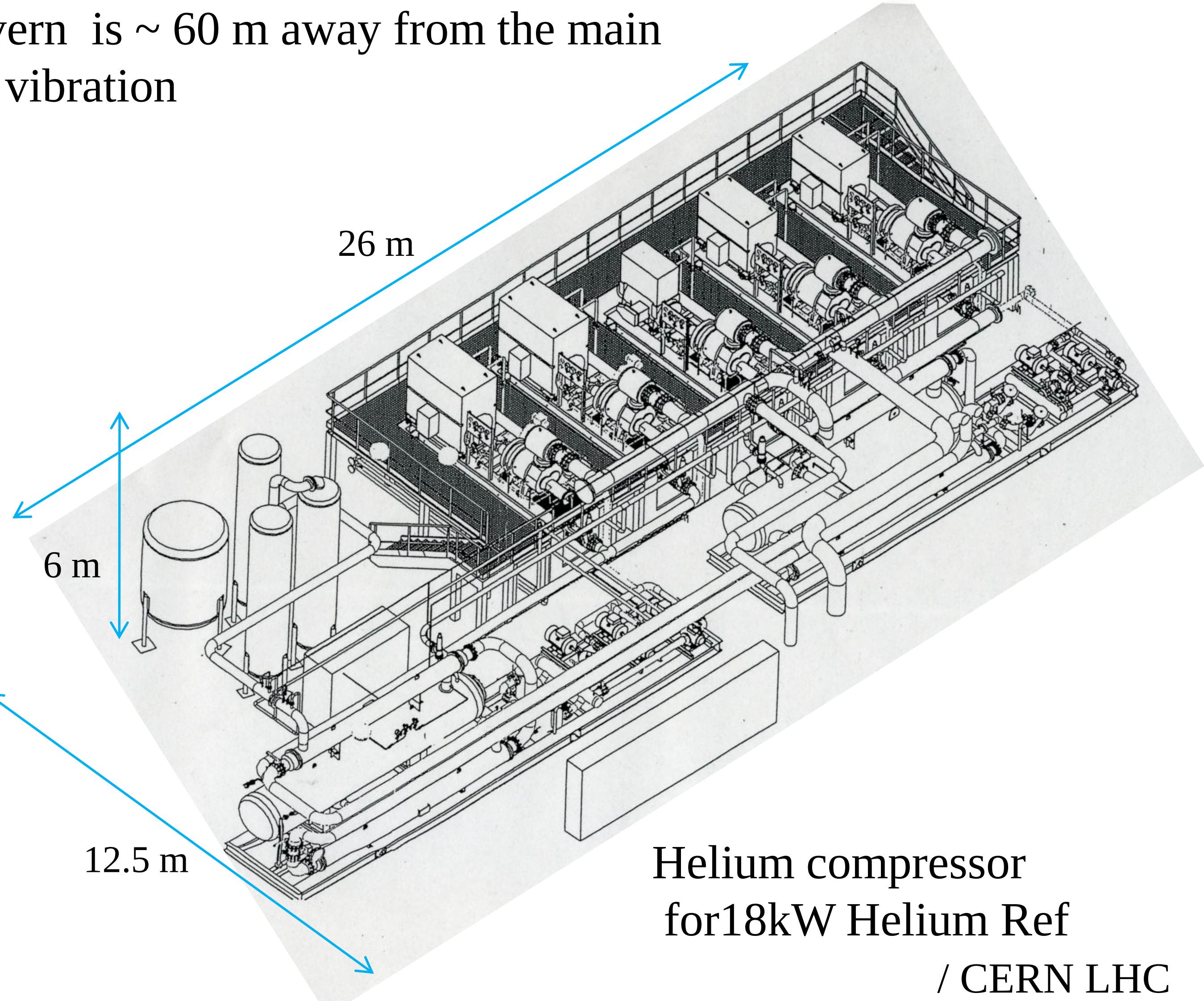
- Temporary size of the cryogenic cavern is given here as for starting point.
- To decide the shape and size of cavern, we need the detailed design study of the main components and these layout in the cavern.
- We must keep contact with cryogenic experts who designed, constructed and has long operation experience of similar system.
- We need close collaboration with industry to carry out the design study.
- In designing the cryogenic system we must care about the safety and maintenance.



Helium Compressor Unit

- 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

Compressor + Motor
5 m x 1.9 m x 2 m H



Helium compressor
for18kW Helium Ref
/ CERN LHC

Figure 3 Compressor station of 18 kW @ 4.5 K cryogenic refrigerator

4K Ref. Cold Box for LHC

Size of 4K cold box
Linde 18kW@ 4.5K

D4m x L18 m

(a) (b)

Figure 4 Coldboxes of 18 kW @ 4.5 K cryogenic refrigerators by Air Liquide (a) and Linde (b)

4.5K + 1.8K Cold Box and Distribution Box for LHC

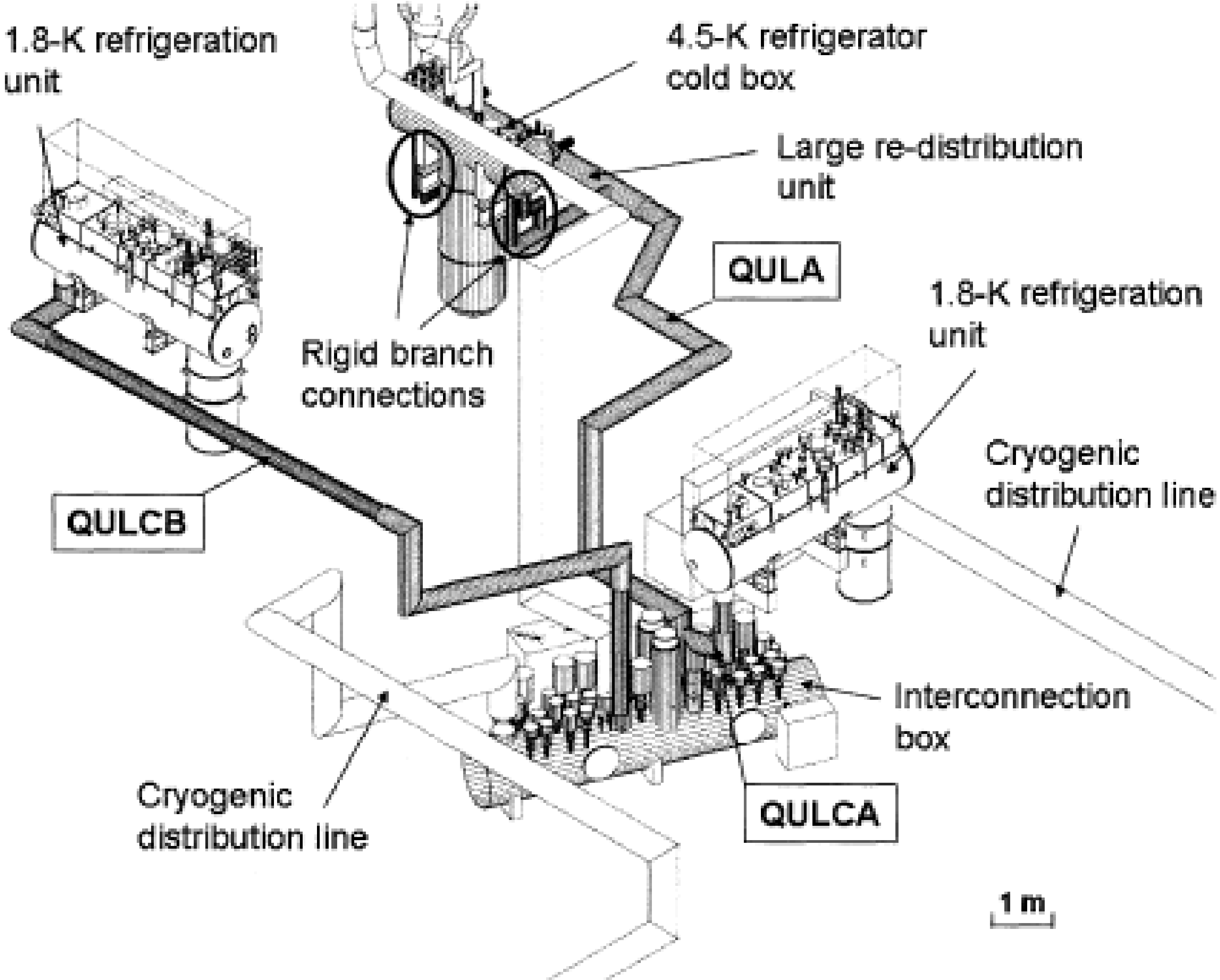
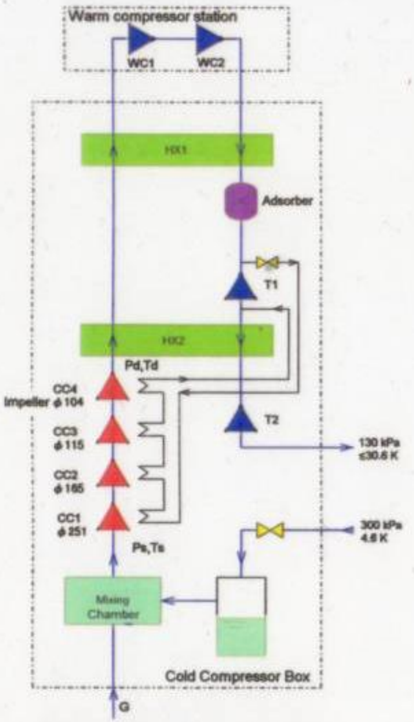
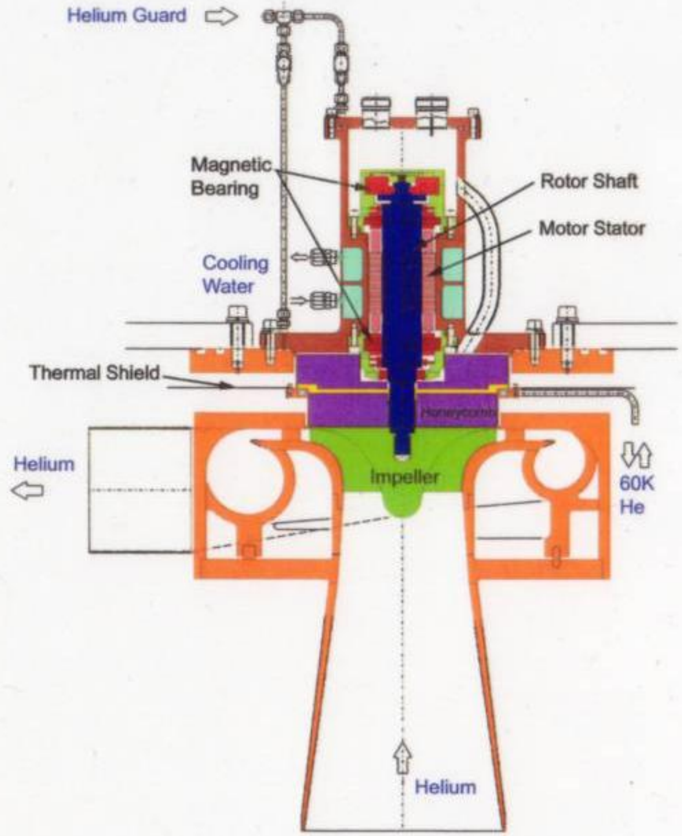


FIGURE 1. Cavern environment with all cryogenic equipment and distribution lines (LHC point 8).

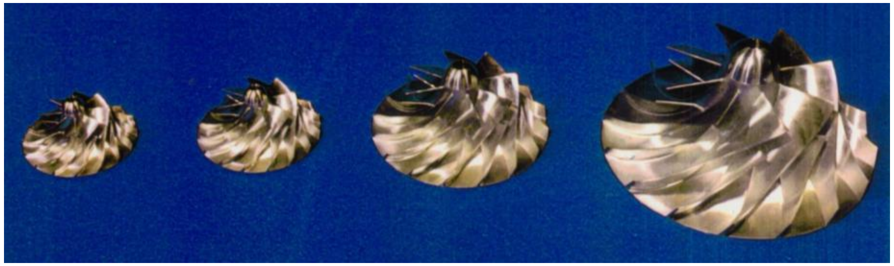
Cold Compressor for LHC 1.8K Refrigerator



Mode	Installed	Normal	Low intensity
Ps kPa	1.40	1.46	1.47
Ts K	3.96	3.95	4.20
Pd kPa	62.2	42.2	33.2
Td K	27.35	21.83	20.77
G g/s	125.7	84.69	63.89



IHI's four-stage cold compressor system fulfills the various operation modes required in 1.8K refrigeration unit of LHC



Size of Impeller

ϕ 104

ϕ 115

ϕ 165

ϕ 251

Storage of Helium Inventory

ILC Cryogenic Systems Reference Design
T.J. Peterson et al.
CEC Vol. 53

- Required Liquid Helium ~ 650,000 L

- Storage as gas:
  standard 100 m^3 gas storage tank (D3 m x L15 m)
  ~ 250 units

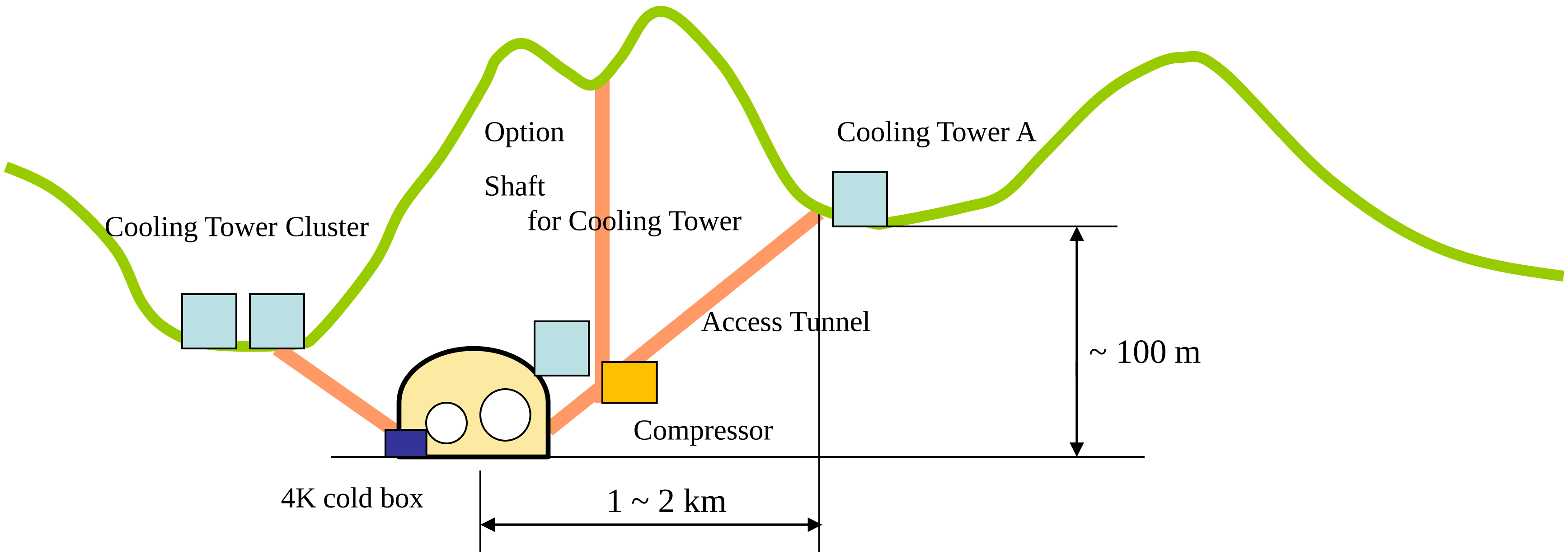
- Storage as liquid:
  ~50,000 L liquid helium Dewar (D3 m x L10 m)

Vaporization loss:

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

Small refrigerator can be used as "Baby-Sitter"

Conceptual Design of Water Cooling System



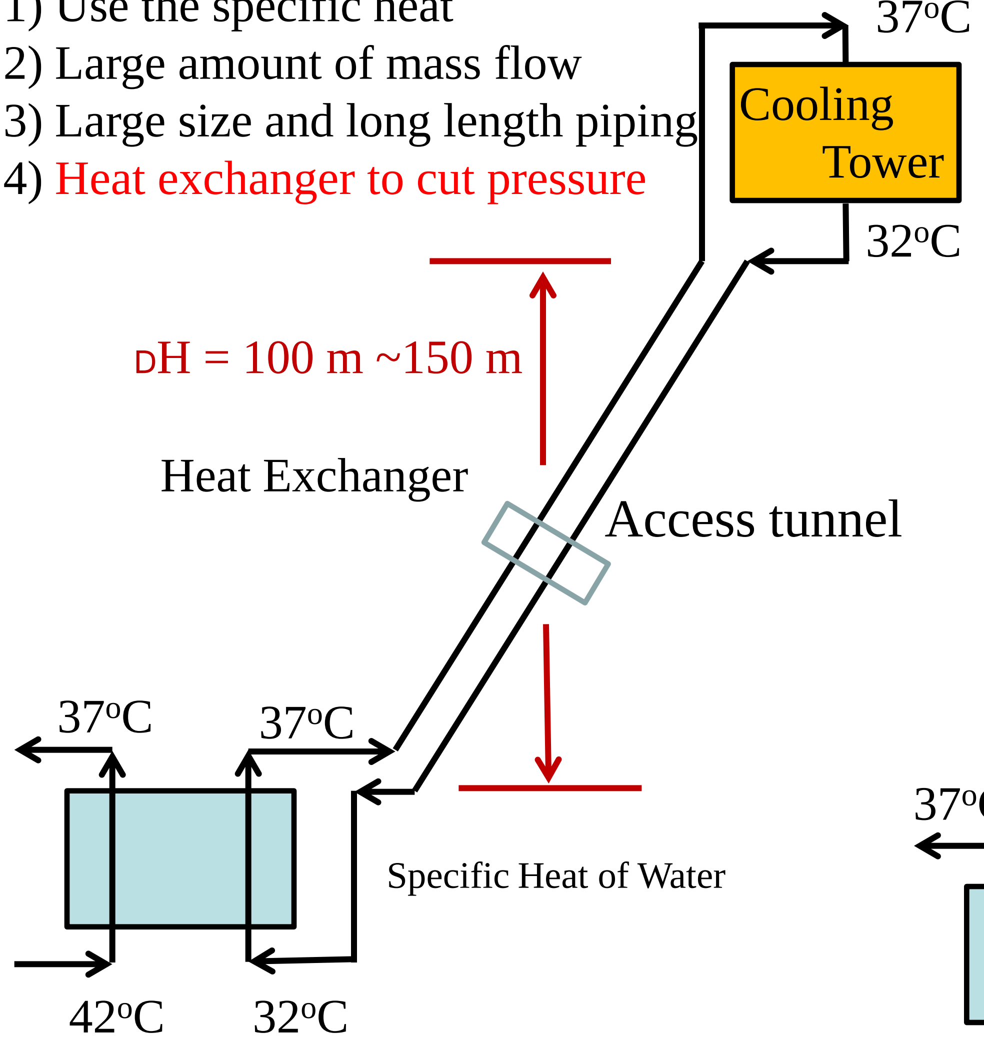
1) Cooling tower at the entrance of access tunnel can support cooling of underground 2 cryogenic plants.
2) Cooling tower cluster can support cooling of ~ 8km long distributed heat load. The cooling water circulate in 900 mm in diameter pipe.
3) By installation of the cooling tower in the tunnel, we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

Extraction of heat from the tunnel (1/2)

Plan A

Circulation of water

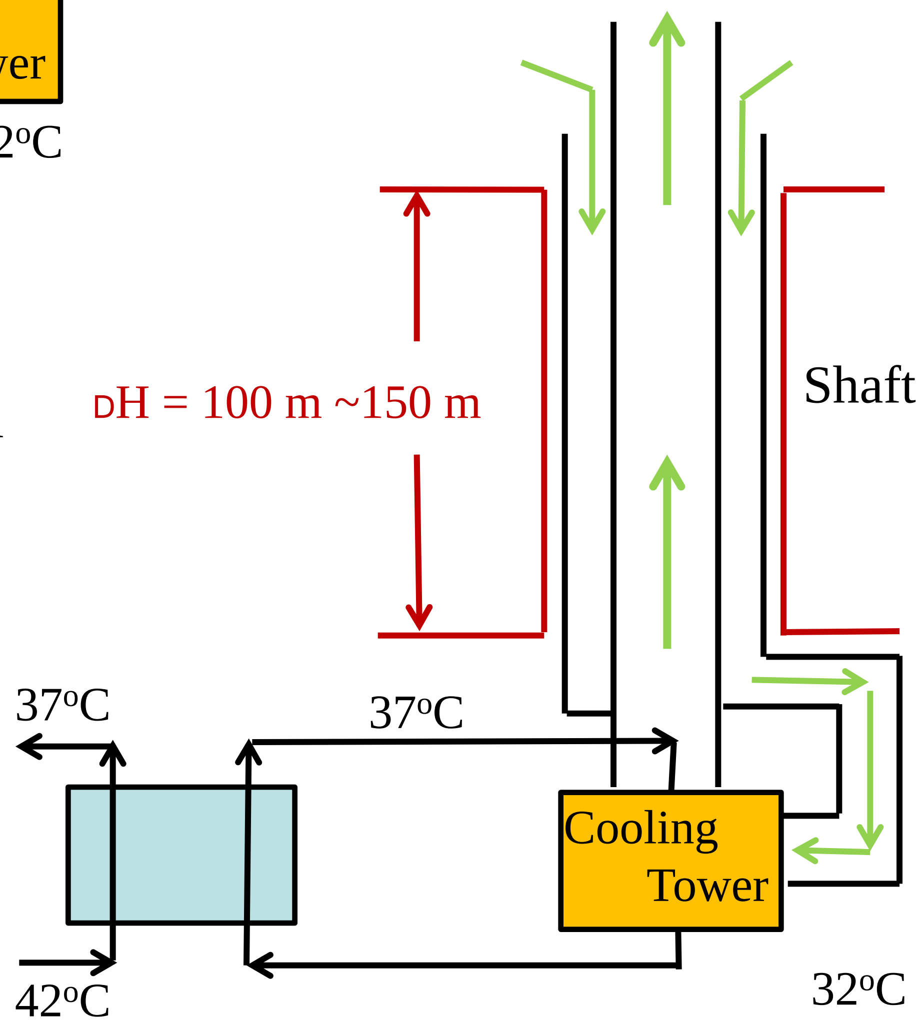
1) Use the specific heat
2) Large amount of mass flow
3) Large size and long length piping
4) Heat exchanger to cut pressure



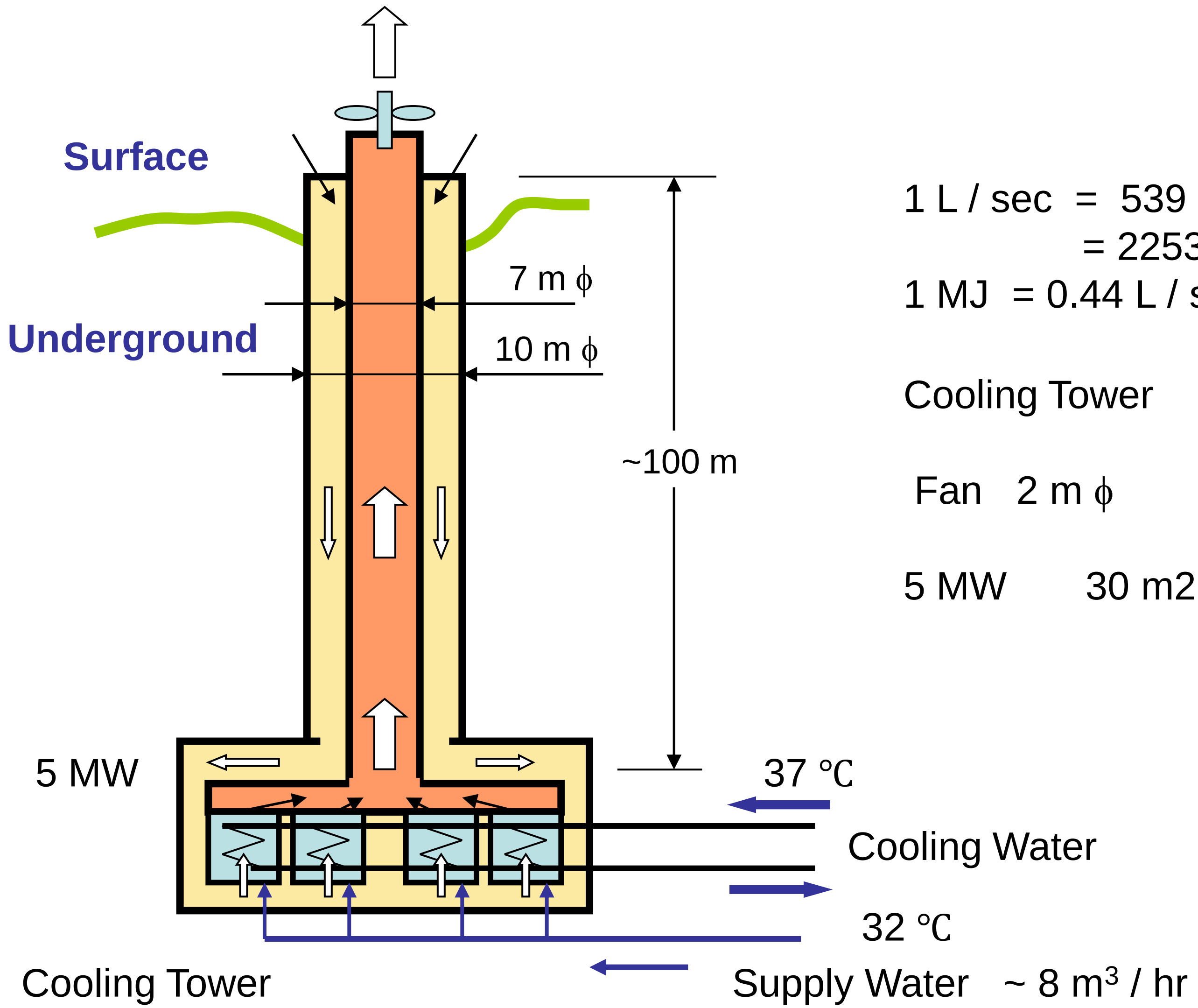
Plan A’

Underground Cooling Tower

1) Eliminate the heat exchanger
2) Need large dia. shaft



Conceptual Design of Underground Cooling Tower



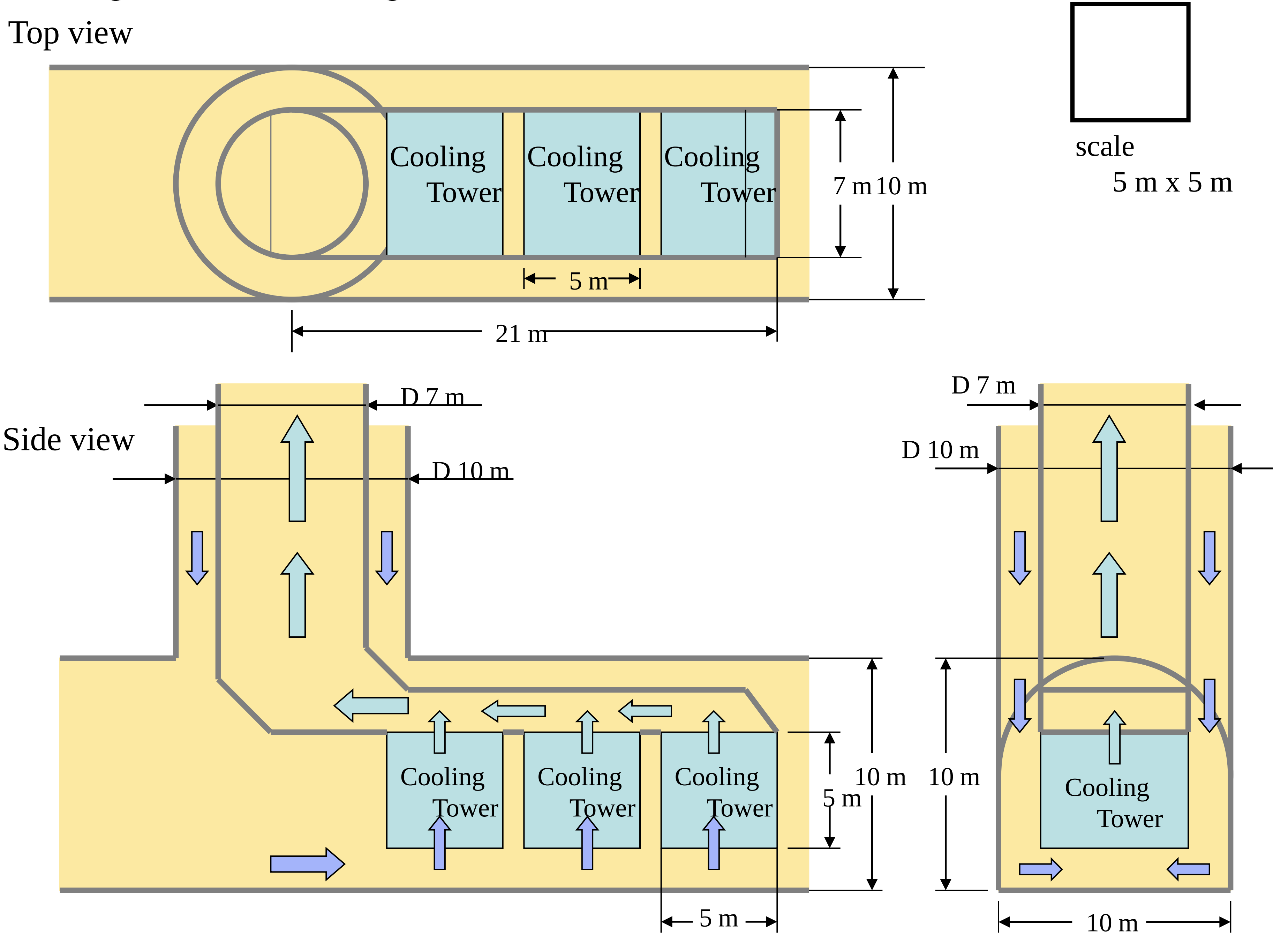
1 L / sec = 539 kcal / sec
= 2253 kW

1 MJ = 0.44 L / sec = 1.6 m3 / hr

Cooling Tower

Fan	2 m ϕ	~ 3 m^2	0.5 MW
5 MW	30 m2	60 m2	~ 9 m ϕ

Underground Cooling Tower

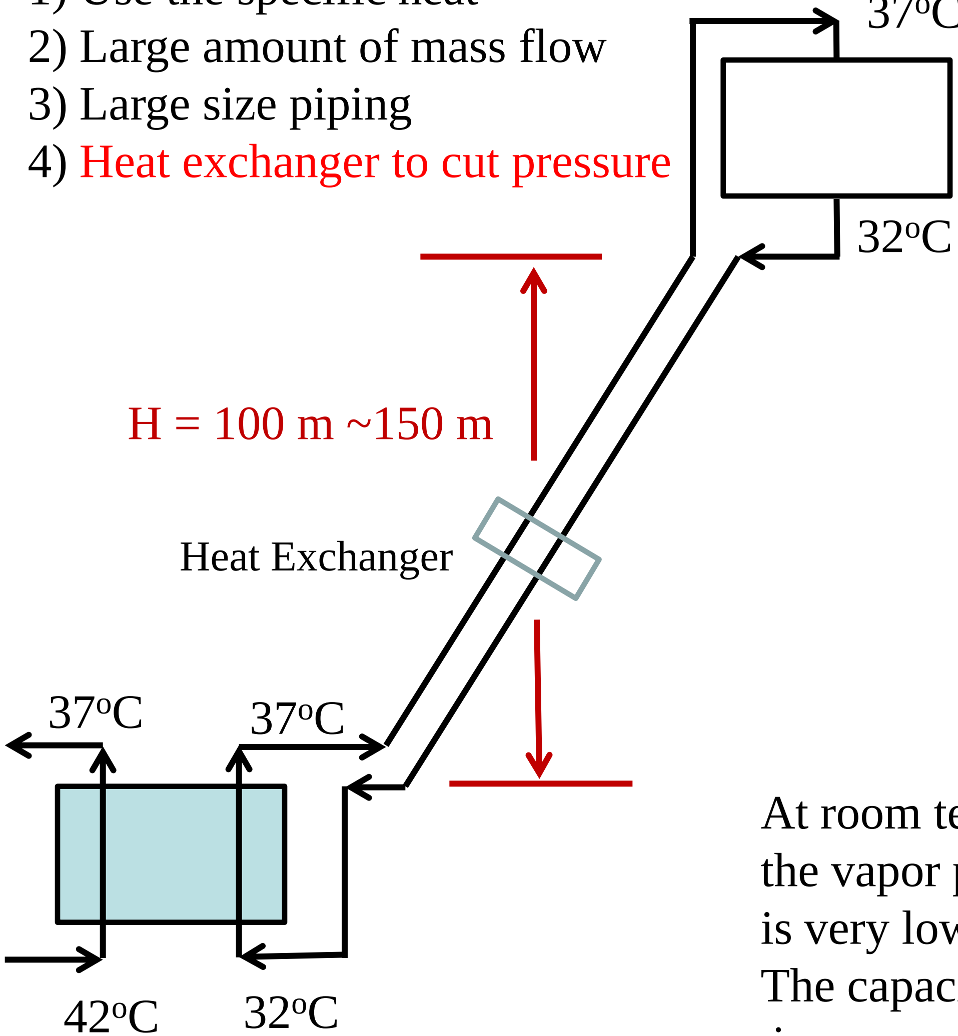


Extraction of heat from the tunnel (1/2)

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

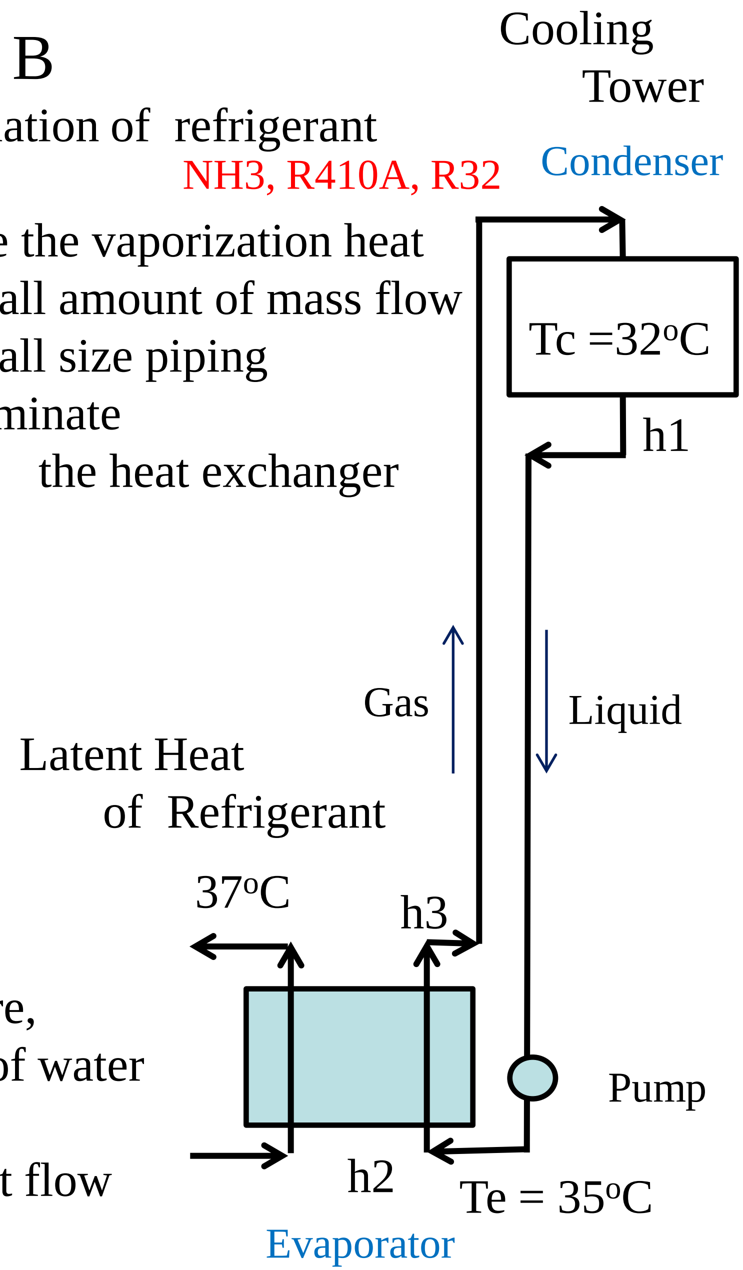


Plan B

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



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

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

Motor power for circulation of water and 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

Summary & Future Plan

- 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.
- 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.