RF Cluster Scheme

Application to Asian Sample Site

2008.11.17

KEK
Atsushi Enomoto

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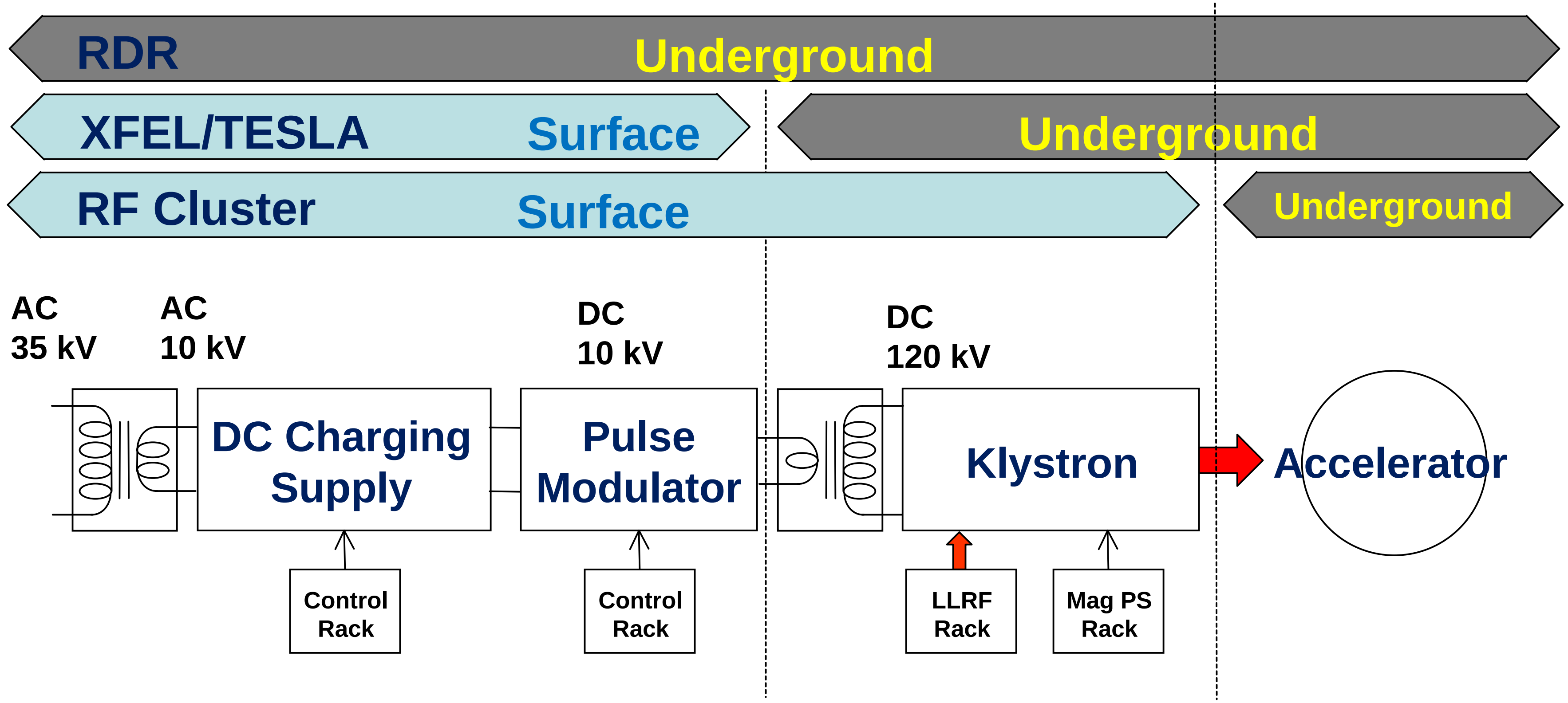
- Introduction – understand the proposal
- Application to Asian Sample Site
- Cost Impact on Civil in Asian Sample Site

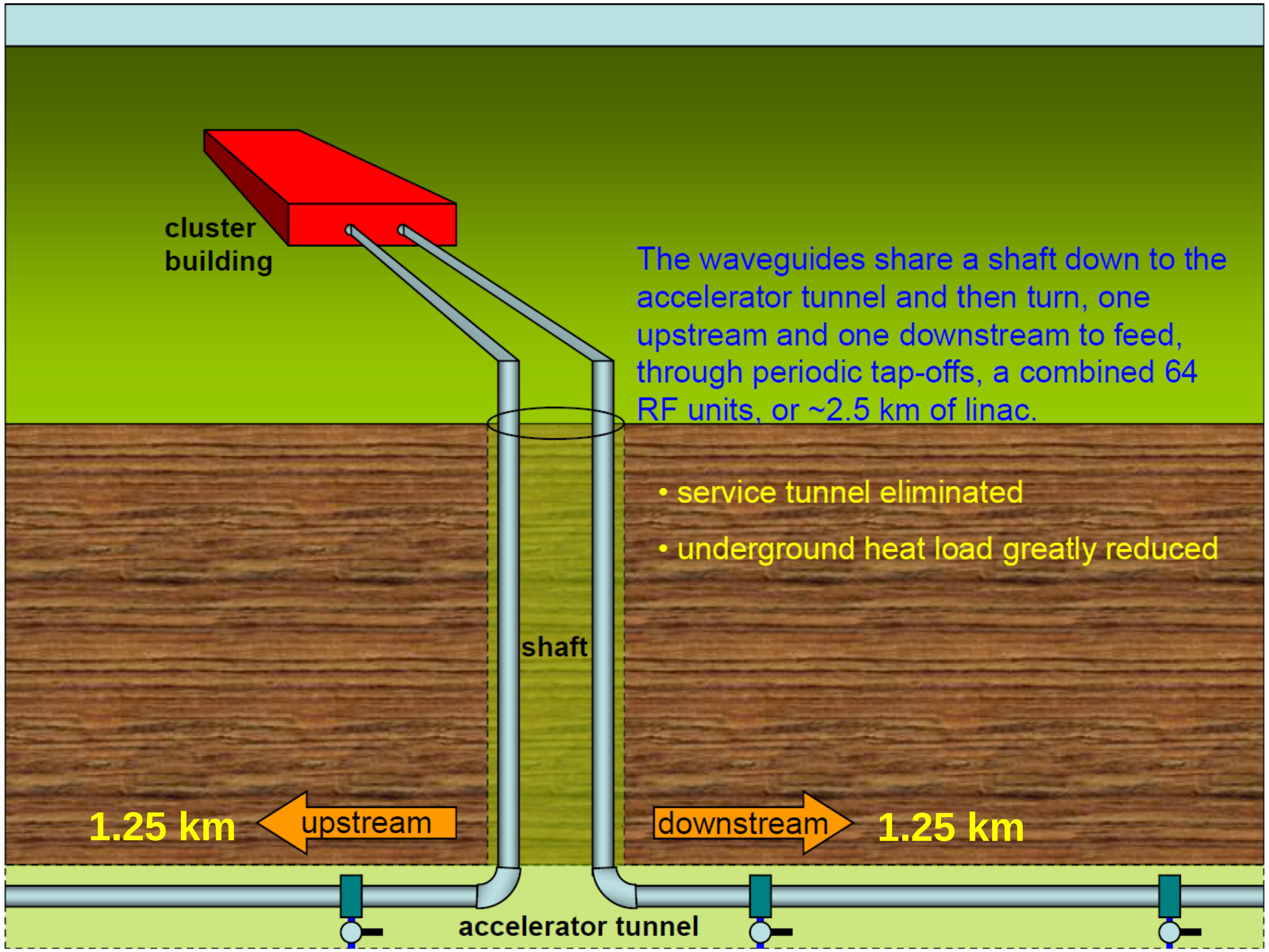
Introduction

RF System Location



- **To reduce underground tunnel, part /full RF system shifted on the ground**

Overall View of the RF Cluster Scheme

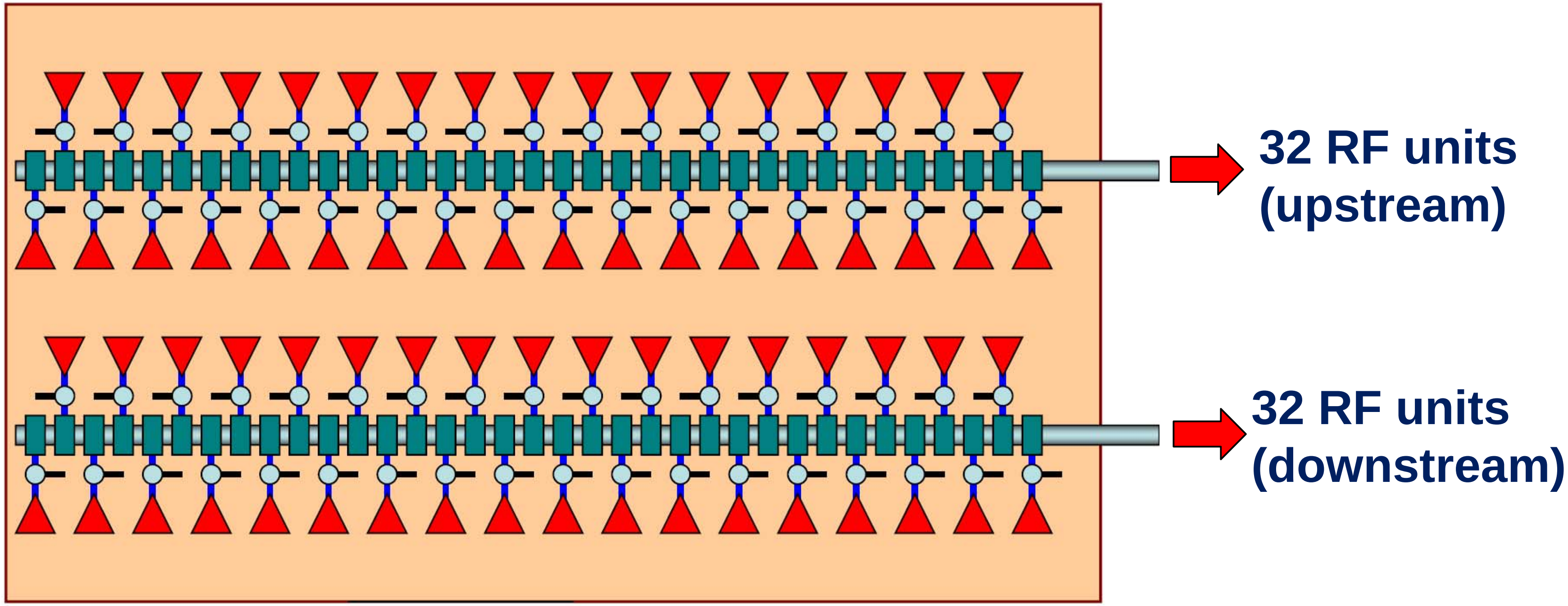


- One RF cluster feeds RF along ~2.5 km (1.25 km for each sides)

Ground Station for the Clustered RF sources

Cluster Layout

Clusters of 70 10 MW klystrons housed, with modulators, in a single building on the surface, feed 350 MW into each of two ~0.5 m diameter evacuated circular waveguides.



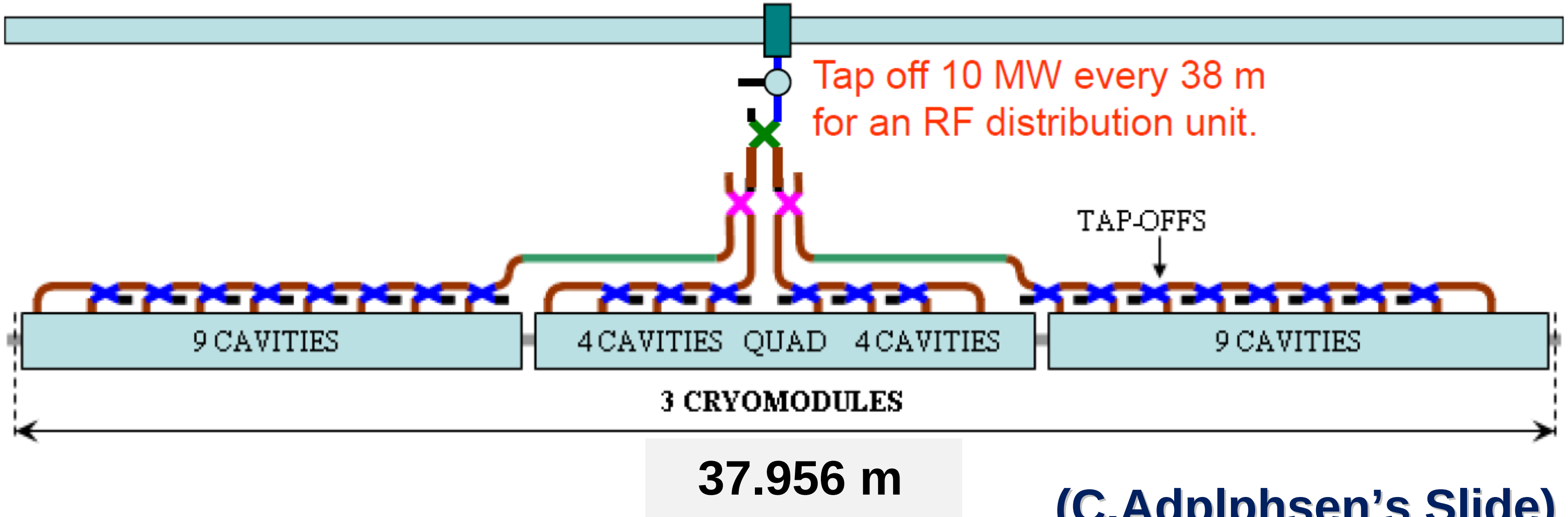
- One RF cluster feeds 64 RF units.

RF feeding along the underground tunnel

Local Distribution

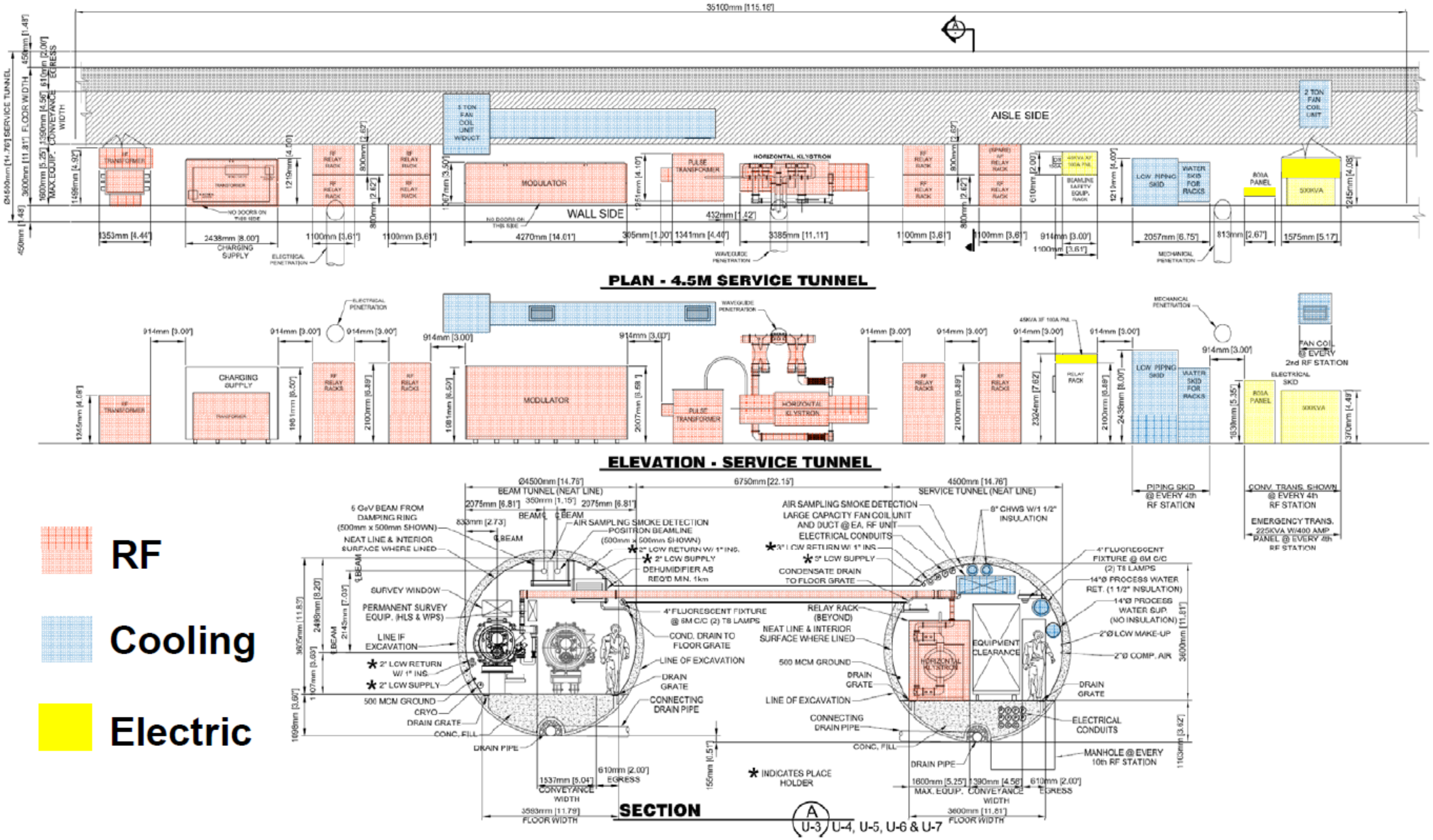
(remains essentially the same)

Each tap-off from the main waveguide feeds 10 MW
through a high power window and probably a circulator or switch
to a local PDS for a 3 cryomodule, 26 cavity RF unit (as shown for baseline).



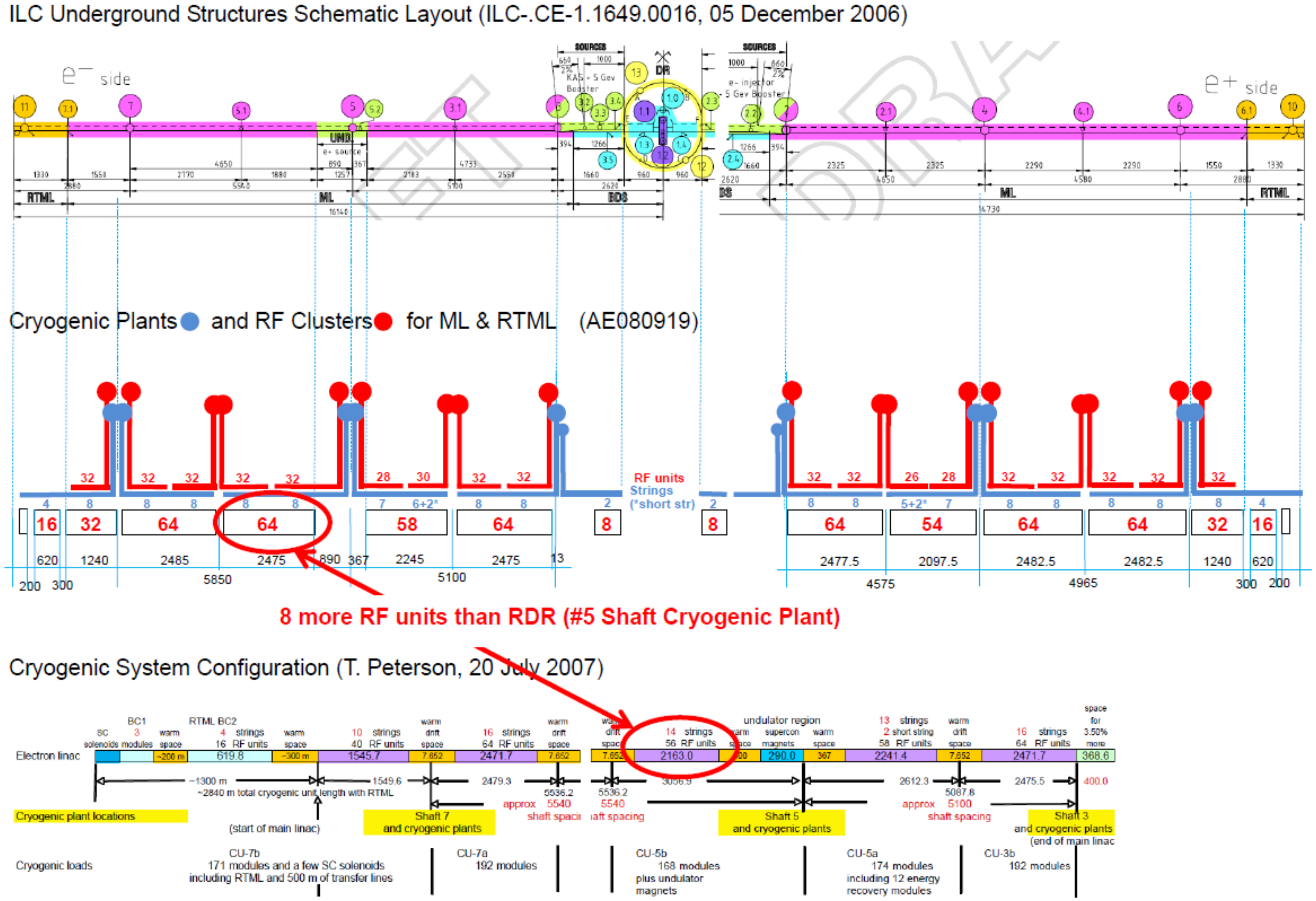
(C.Adplphsen's Slide)

RDR Service Tunnel Layout



- **RF Cluster system move almost all equipment to the ground surface**

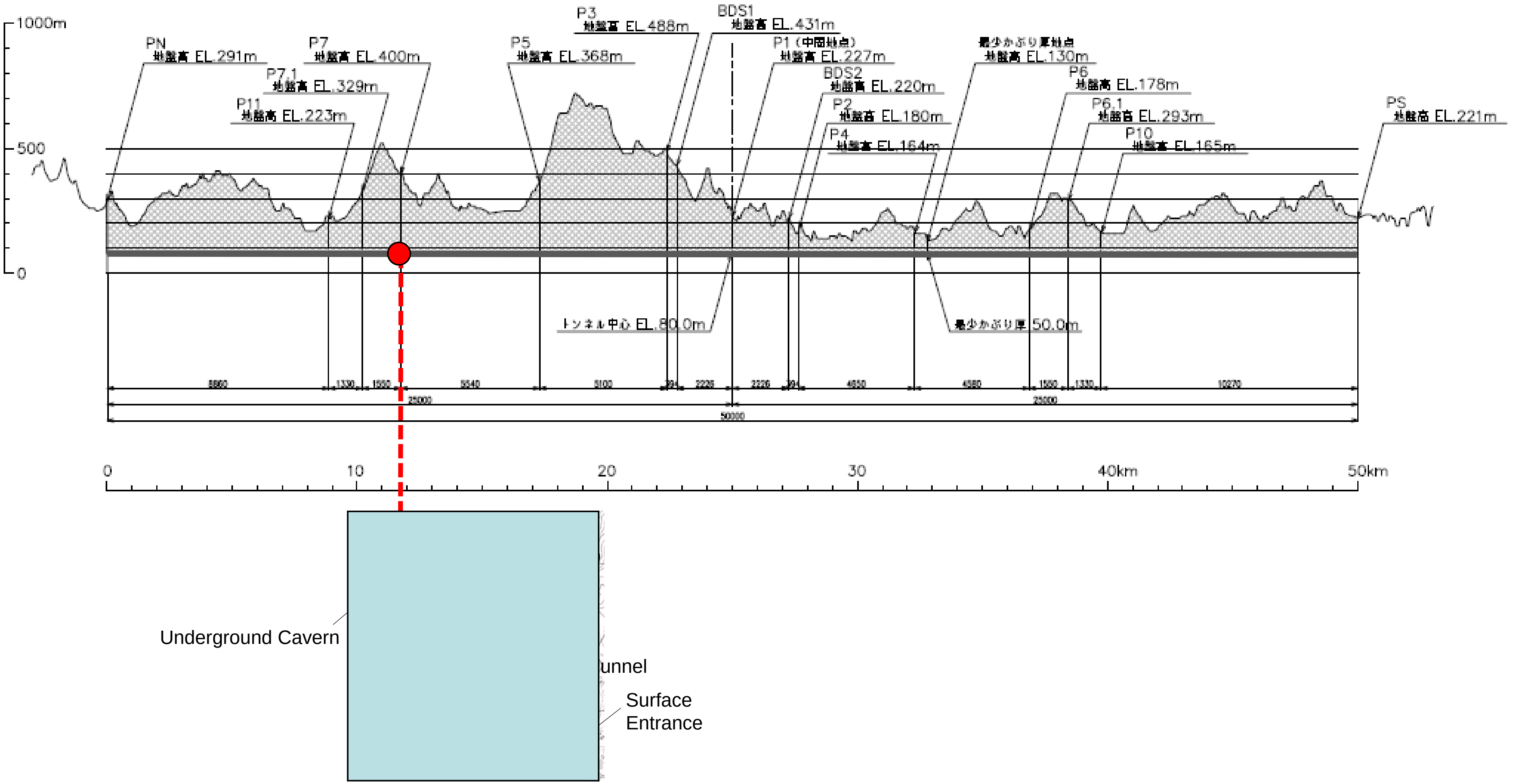
RDR Service Tunnel Layout



- **RF Cluster system move almost all equipment to the ground surface**

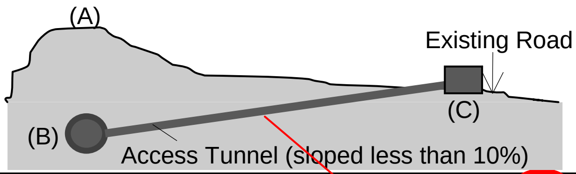
Application to Asian Sample Site

Access to Beam Tunnel in Asian Sample Site



- The Asian terrain is not flat compared with Americas or European SSs.
- In RDR, sloped tunnels are used to access the underground except IR.

RDR



Point ID	Elevation		Overburden above Beam Tunnel = (A)-(B)	Elevation	Drop from Entrance to Beam Tunnel = (C)-(B)	Length from Entrance to Beam Tunnel
	(A) Surface	(B) Beam Tunnel		(C) Entrance		
7	400	80	320	204	124	1,540
5	368	80	288	226	146	1,608
3	488	80	408	238	158	1,706
2	180	80	100	156	76	1,198
4	164	80	84	117	37	652
6	178	80	98	165	85	934
Average	296	80	216	184	104	1,273

- **Very long access length is problem to be solved.**
- **RF waveguide length exceeds 2 km (1.25 km @beam tunnel + 1.27 km @access) !**

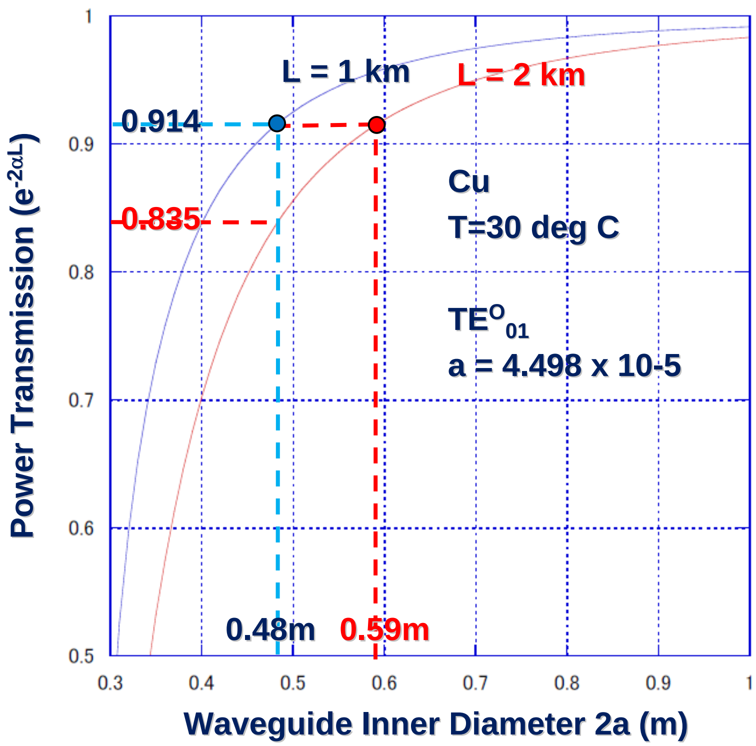
Attenuation Of RF Through Cylindrical Waveguides

$$\mathrm{TE}^{\circ}_{01}: \alpha = \frac{R_s}{Z_0} \frac{1}{\sqrt{k_0^2 - (\chi_{01}/a)^2}} \frac{\chi_{01}^2}{k_0 a^3} \Omega$$

α: attenuation constant (neper/m)
R_s: skin resistance (Ω)
Z_0: intrinsic impedance ~377 Ω
k_0: propagation constant in free space
$k_c = X_{01}/a$: cut-off propagation constant
X_{01}= 3.832 for TE01 mode
2a: inner diameter of cylindrical waveguide

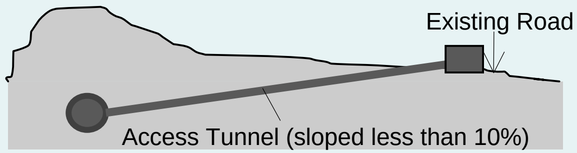
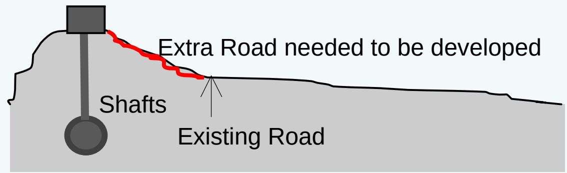
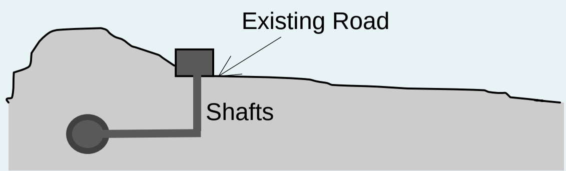
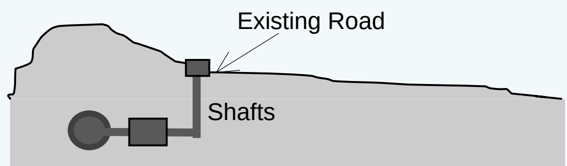
Cu
ρ_{20}=1.72 x 10^{-8} Ωm
ρ_{0-100}=4.3 x 10^{-3} /deg

TE^{O}_{01}
α = 4.498 x 10^{-5} (2a = 0.48 m)
α = 2.233 x 10^{-5} (2a = 0.59 m)
@T=30 deg C

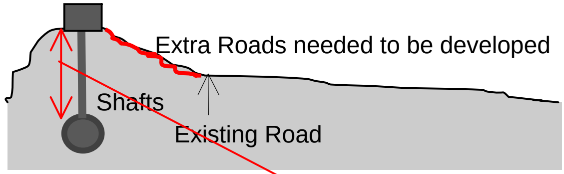


Waveguides which are ~1 km longer than those in Americas site have to be used,
with two choices,
- to use 0.48-m diameter waveguides and 8% more RF sources;
- to use 0.59-m diameter waveguides.

Possibilities of reducing distance from surface to underground tunnel
----- though it may cost higher

Case	Access way	Schematic Layout
RDR	Sloped Tunnel	
Case B	Shaft	
Case C	Shaft + Horizontal Tunnel (surface hall)	
Case D	Shaft + Horizontal Tunnel (underground hall)	

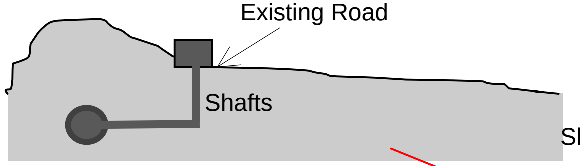
Case B

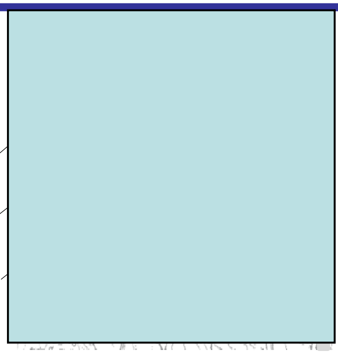


Point ID	Elevation		Overburden above Beam Tunnel = (A)-(B)	Elevation	Drop from Entrance to Beam Tunnel = (C)-(B)	Length from Entrance to Beam Tunnel
	(A) Surface	(B) Beam Tunnel		(C) Entrance		
7	330	80	250	204	124	1,540
5	344	80	264	226	146	1,608
3	493	80	413	238	158	1,706
2	188	80	108	156	76	1,198
4	173	80	93	117	37	652
6	161	80	81	165	85	934
Average	282	80	202	184	104	1,273

- **Increase of construction costs for longer shafts and access roads from the existing road to the shaft entrances.**

Case C

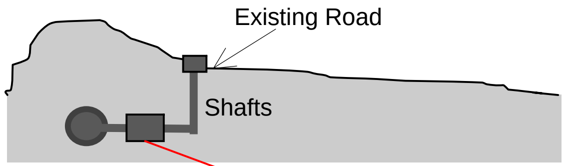




Point ID	Entrance Elevation	Access Distance		
		Drop	Horizontal Distance	total
7	300	220	560	780
5	226	210	526	736
3	238	170	1,330	1,500
2	156	70	130	200
4	117	100	180	280
6	165	100	140	240
Average	200			623

- **Increase of waveguide length might be about half of sloped tunnel case.**
- **Construction cost of shafts plus horizontal tunnels should be compared with entire sloped tunnels.**

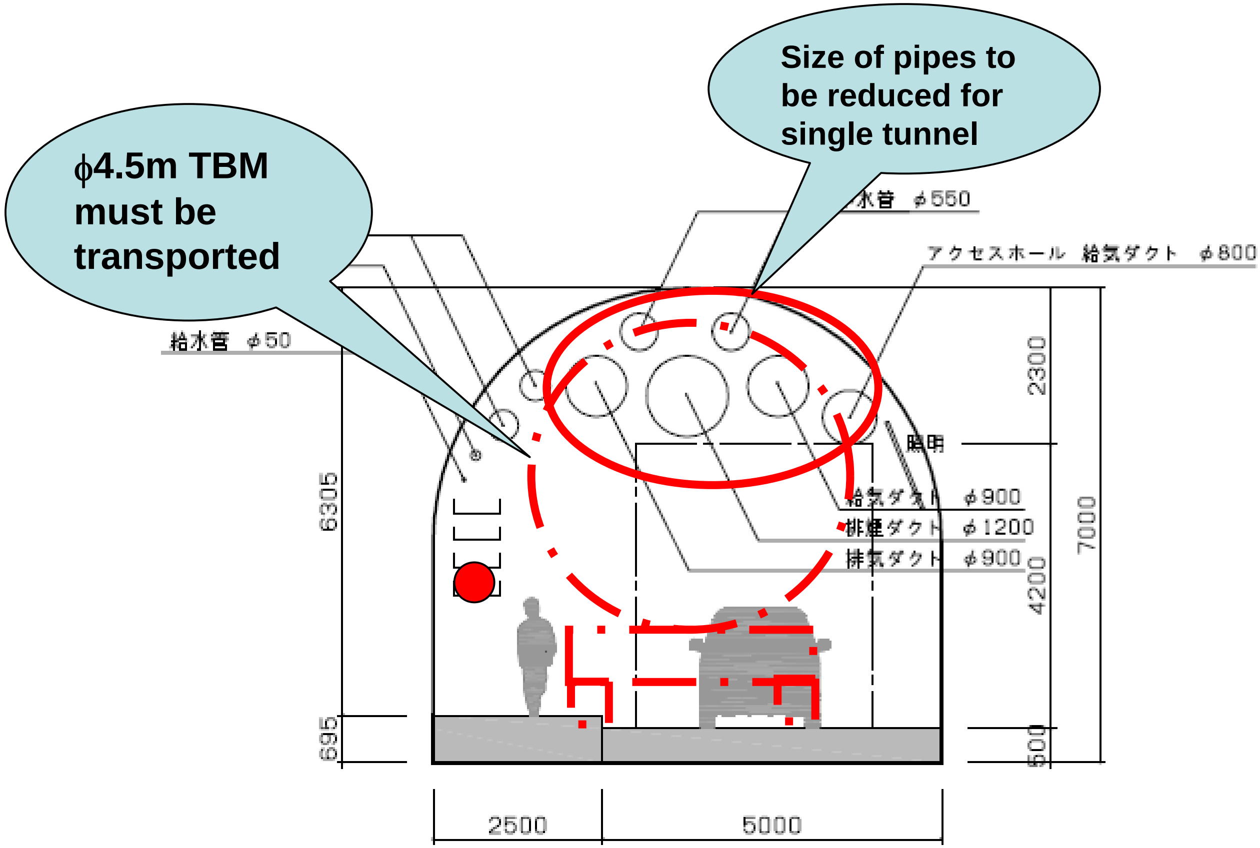
Case D



Point ID	Entrance Elevation	Access Distance		
		Drop	Horizontal Distance	total
7	300	220	<560	780
5	226	210	<526	736
3	238	170	<1,330	1,500
2	156	70	<130	200
4	117	100	<180	280
6	165	100	<140	240
Average	200		<478	

- **Increase of waveguide length might be about half less than Case A.**
- **Construction cost of shafts plus horizontal tunnels should be compared with entire sloped tunnels.**

RDR access tunnel has enough space for waveguides



- Access tunnels at points 7, 5, 3, 2, 4, 6 are used, four more access tunnels have to be newly excavated.

Changes of Electric Distribution

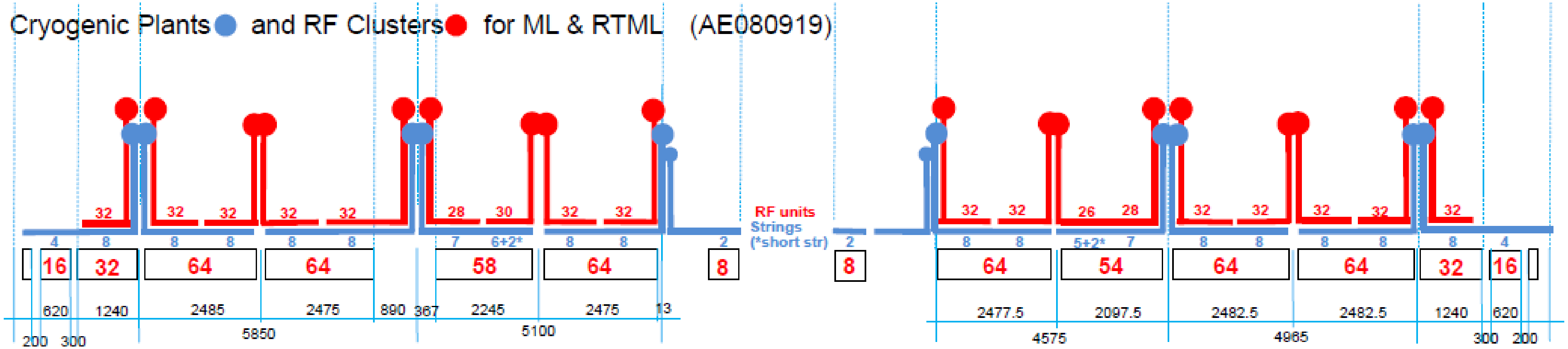


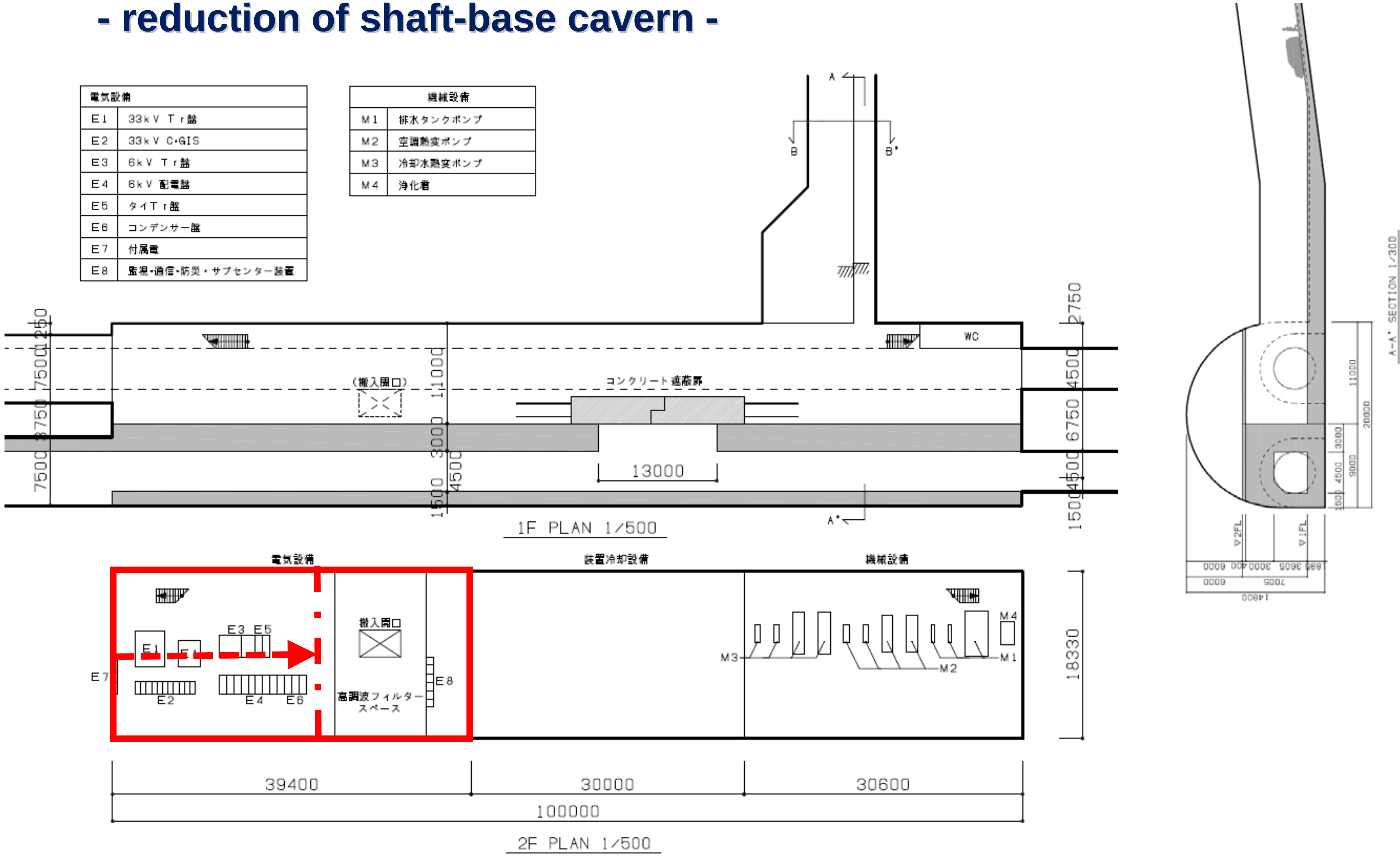
TABLE 4.3-1
Estimated nominal power loads (MW) for 500 GeV centre-of-mass operation.

Area System	RF Power	Conventional Power				Emer Power	Total (by area)
		Conv	NC Magnets	Water Systems	Cryo		
Main Linac	75.72	13.54	0.78	9.86	33.0	0.4	134.21
Totals (by system)	102.0	32.5	25.6	17.9	36.9	1.4	216.3

- **Most electric power will be distributed to surface facilities except for beam line equipment, part of cryogenic system (ex. cold boxes), and service to maintain underground.**
- **Area for substation at shaft-base cavern will be reduced.**

Changes of Electric Distribution

- reduction of shaft-base cavern -



電気設備	
E1	33kV Tr盤
E2	33kV C・GIS
E3	6kV Tr盤
E4	6kV 配電盤
E5	タイTr盤
E6	コンデンサー盤
E7	付属電
E8	監視・通信・防災・サブセンター装置

機械設備	
M1	排水タンクポンプ
M2	空調熱交ポンプ
M3	冷却水熱交ポンプ
M4	浄化槽

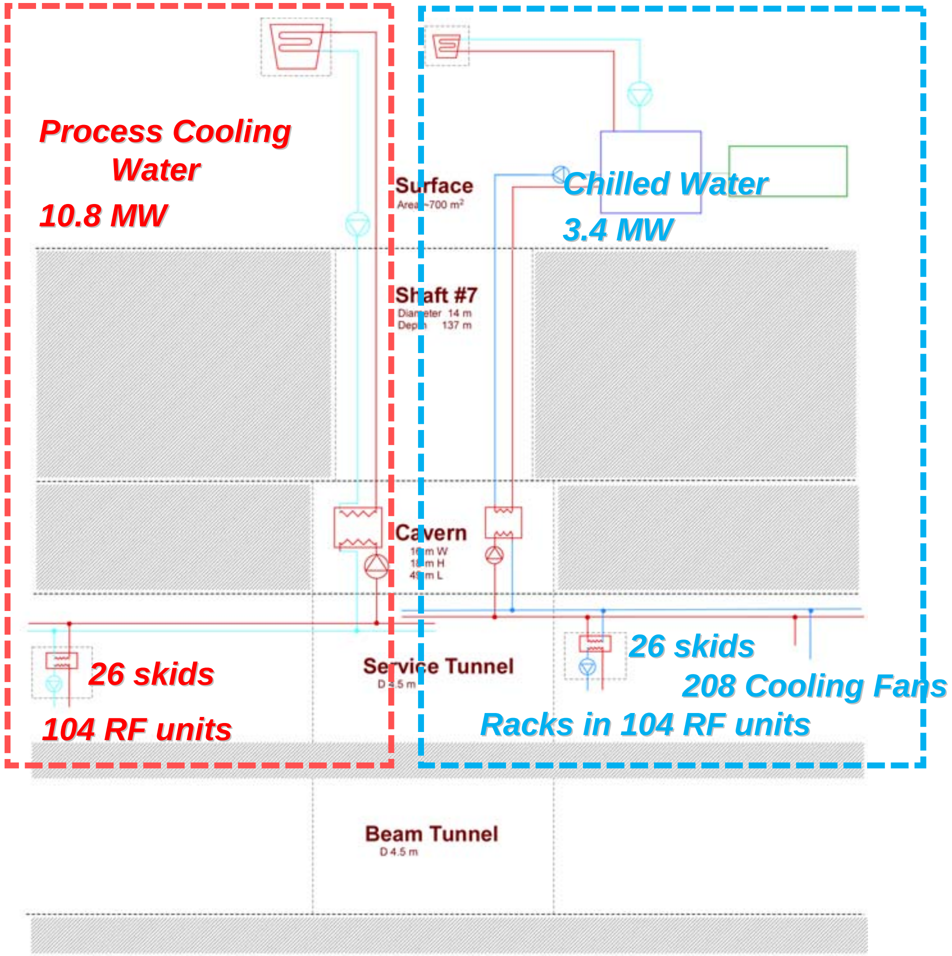
Changes of Cooling System

Dec 14 2007

WATER AND AIR HEAT LOAD (all LCW) and 9-8-9 ML

MAIN LINAC - ELECTRON & POSITRON					To Low Conductivity Water	to Chilled Water	keith Jobe load to Air Nov 22 06	
Components	Quantity Per 36m	Location	Total Heat Load (KW)	Average Heat Load (KW)	Heat Load to Water (KW)	Heat Load to Water (KW)	Power fraction to Tunnel Air (0-1)	Power to Tunnel Air (KW)
Non-RF Components								
LCW Skid Pump 1 per 4 rf -Motor/Feeder Loss	0.25	Service Tunnel	0.60	0.60	0	0	1.00	0.60
I^2R Loss and Motor Loss (misc)	1	Service Tunnel	8.99	8.22	0	0	1.00	8.22
Fancoils (5 ton Chilled Water) 1.5 Hp	2	Service Tunnel	2.91	2.91	0	0		
Rack Water Skid	0.25	Service Tunnel	0.20	0.20	0	0	1.00	0.20
Lighting Heat Dissipation ~1.3W/sf		Service Tunnel	1.65	1.65	0	0	1.00	1.65
AC Pwr Transformer 34.5-.48 kV	0.25	Service Tunnel	2.00	2.00	1.50	0	0.25	0.50
Emerg. AC Pwr Transformer 34.5-.48 kV		Service Tunnel	1.00	1.00	0	0	1.00	1.00
RF Components								
RF Charging Supply 34.5 Kv AC-8KV DC	1/36 m	Service Tunnel	4.0	4.0	2.8	0	0.3	1.2
Switching power supply 4kV 50kW	1/36 m	Service Tunnel	7.5	7.5	4.5	0	0.4	3.0
Modulator	1/36 m	Service Tunnel	7.5	7.5	4.5	0	0.4	3.0
Pulse Transformer	1/36 m	Service Tunnel	1.0	1.0	0.7	0	0.3	0.3
Klystron Socket Tank / Gun	1/36 m	Service Tunnel	1.0	1.0	0.8	0	0.2	0.2
Klystron Focusing Coil (Solenoid)	1/36 m	Service Tunnel		4.0	5.5	0	0.1	0.4
Klystron Collector	1/36 m	Service Tunnel	58.9	47.2	45.8	0	0.0	1.4
Klystron Body & Windows	1/36 m	Service Tunnel			4.2	0		
Relay Racks (Instrument Racks)	1/36 m	Service Tunnel	10.0	10.0	0	11.5	-0.2	-1.5
RF Distribution (Attenuators, Loads, Waveguide, Circulators all in series connection)	2/36 m	Service Tunnel			0			0.0
	1/36 m	Service Tunnel			0			1.166
	1/36 m	Penetration			0.676			
	1/36 m	Beam Tunnel			0.0	0		5.9
	26/36 m	Beam Tunnel			2.49	0		0.0
	24/36 m	Beam Tunnel			30.05			0.0
Subtotal RF unit Only			90	82	102.0			
Total RF			107	99	103.5	11.5		21.4

Total Heat load to Air/Chilled water in service tunnel (per RF)	32.9
Total Heat load to LCW (per RF)	103.5
Total Heat load to air in beam tunnel (ignore rock contribution for now)	5.9



- ~30% of the heat loads remain in the undergroud.
- Area for substation at shaft-base cavern and RF skids will be reduced in capacity but not eliminated.

Waveguide Temperature Issue - without cooling water -

$$-\frac{dP}{dx} = 2\alpha P$$

$$P = P_0 e^{-2\alpha x}$$

-dP/dx: lossed microwave power per unit length (W/m)
α: attenuation constant (neper/m)
P: transmitted power (W)
P_0: initial power generated by RF cluster (W)
x: transmitted distance (m)

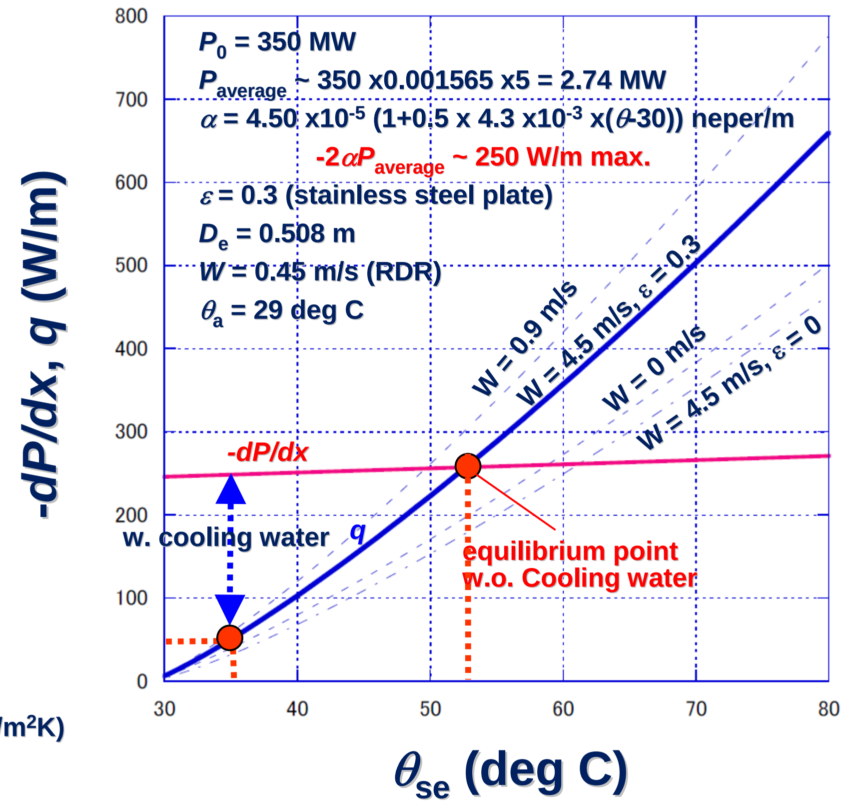
$$q = h_{se}\pi D_e \Delta\theta$$

$$h_{se} = \varepsilon\sigma(T_{se}^4 - T_a^4)/\Delta\theta + 1.19\left(\frac{\Delta\theta}{D_e}\right)^{0.25}\left(\frac{w+0.348}{0.348}\right)^{0.5}$$

$$\Delta\theta = \theta_{se} - \theta_a$$

(JIS A9501)

q: dissipated heat by radiation and convection per unit length (W/m)
h_{se}: heat dissipation constant from surface of horizontal beam pipe (W/m^2K)
D_e: outer diameter of waveguide (m)
θ_{se}: temperature of surface on waveguide (deg C)
θ_a: temperature of ambient air around waveguide (deg C)
ε: radiation efficiency
σ: Stefan-Boltzmann constant 5.67 x10^{-8} ($Wm^{-2}K^{-4}$)
T_{se}: temperature of surface on waveguide (deg K) $= \theta_{se}+273$
T_a: temperature of ambient air around waveguide (deg K) $= \theta_a+273$
w: wind velocity (m/s)



Waveguides radiate ~250 W/m max. or ~9 kW/RF unit max. w/o cooling water;
Expansion of SUS (copper coating inside) pipe will be 240 mm/km for $\Delta\theta$ = 20 deg C.

Changes of Shaft-base Cavern Cooling-water Plants

- reduction of shaft-base cavern (2) -

電気設備	
E1	33kV Tr盤
E2	33kV C·GIS
E3	6kV Tr盤
E4	6kV 配電盤
E5	タイTr盤
E6	コンデンサー盤
E7	付属室
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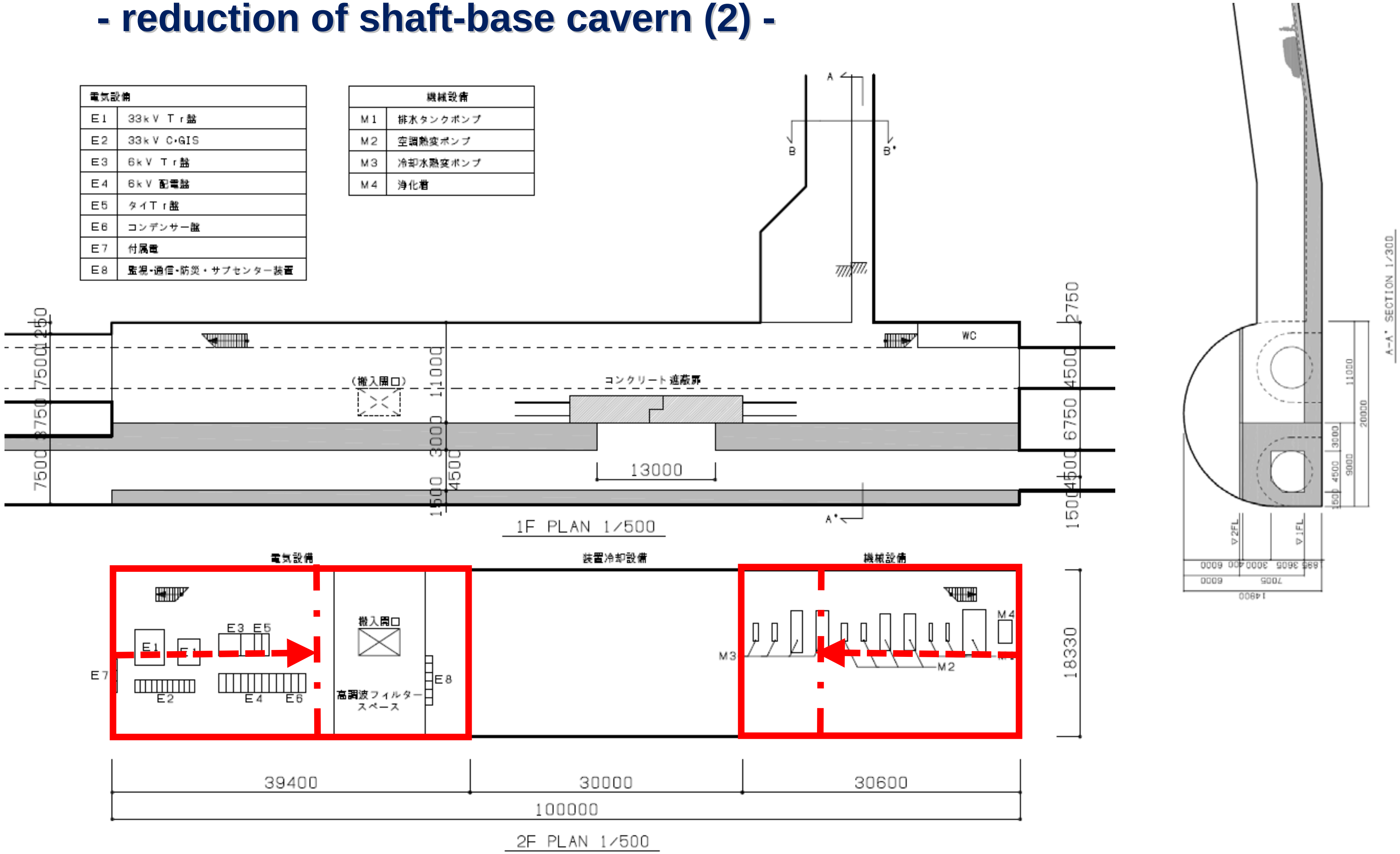
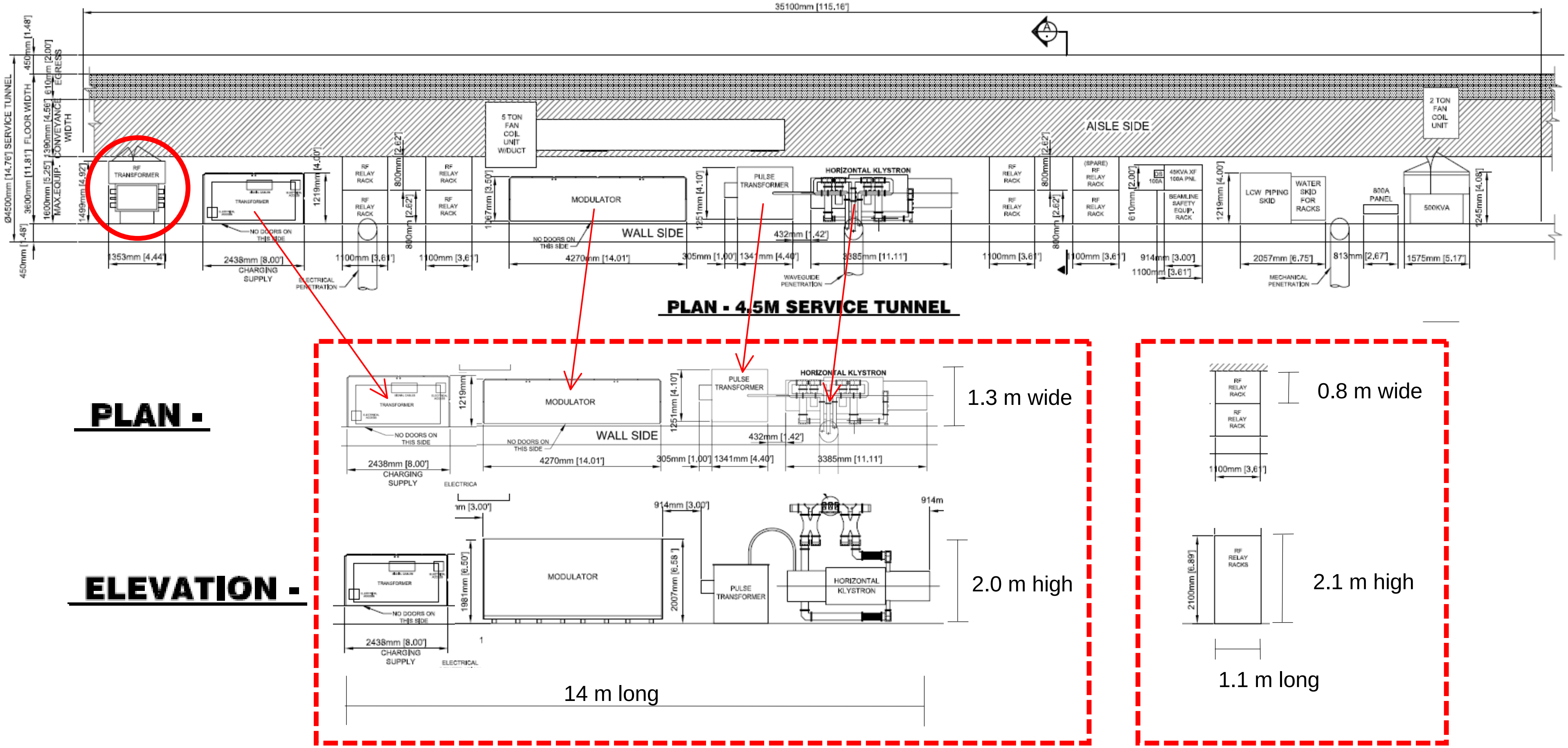


Additional Surface Building - Estimation of RF Source Size -



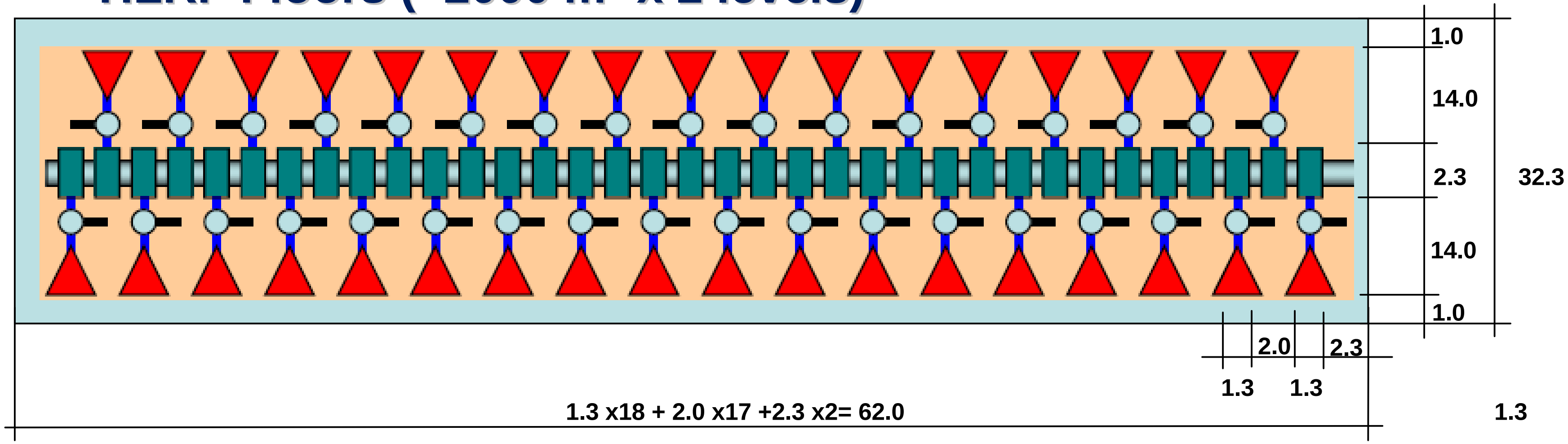
HLRF Unit (14m x 1.3m x 2.0m)

LLRF Unit X 7

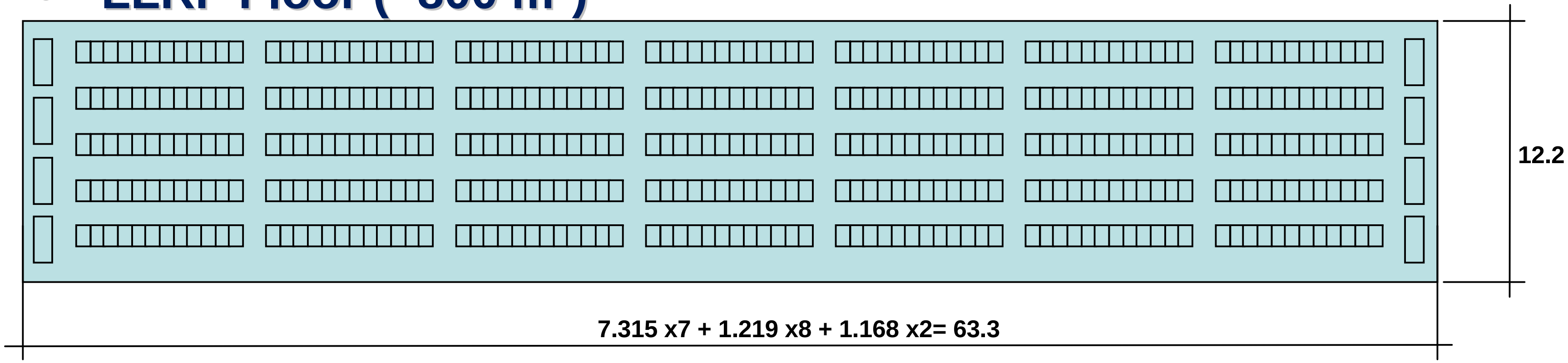
(1.1m x 0.8m x 2.1m)

Cluster Size

- HLRF Floors (~2000 m² x 2 levels)

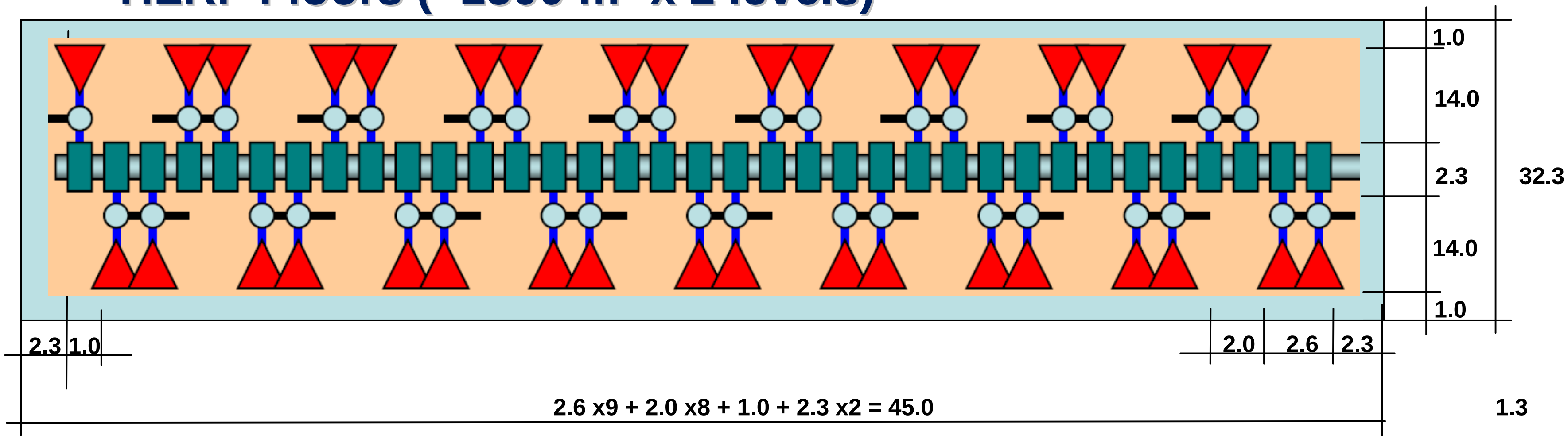


- LLRF Floor (~800 m²)

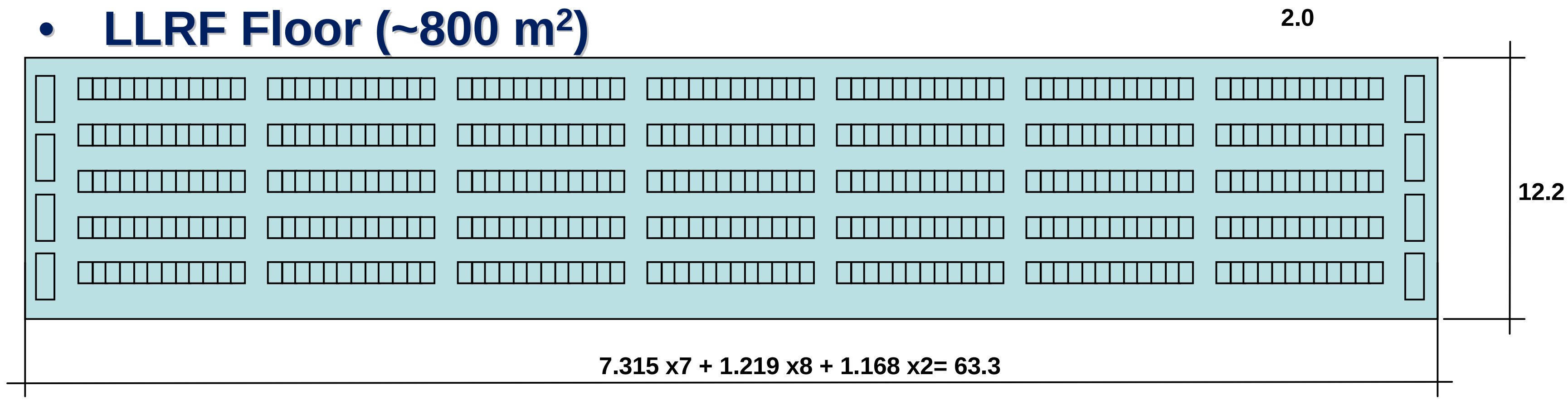


Cluster Size (Compact)

- HLRF Floors (~1500 m^2 x 2 levels)



- LLRF Floor (~800 m^2)



Main Linac Surface Structures (RDR)

ILC PROJECT - SURFACE BUILDINGS ANCILLARY FACILITIES

ASIAN REGION — Draft 4/2/07 — AMERICAS REGION — EUROPEAN REGION

WBS		Building Type / Area System	Shaft Area	Asian: 4-5-6-7+1/2 (2+3) Main linac	Building /shaft	Americas: 4-5-6-7+1/2 (2+3) Main linac	European: 4-5-6-7+1/2 (2+3) Main linac
1.7.3.3.2	1	Detector Assembly	# buildings Tot. surface	0 0		0 0	0 0
1.7.3.3.3	2	Offices for Technical Staff	" "	5 1000	200 m^2	4 1396	5 1000
1.7.3.3.4	3	Electrical building	" "	5 3600	720 m^2	5 695	5 3600
1.7.3.3.4	4	Cooling Tower & Pump Station	" "	5 3250	650 m^2	5 3485	5 3250
1.7.3.3.4	5	Cooling Ventilation building	" "	5 4000	800 m^2	5 2615	5 4000
1.7.3.3.4	6	Beam dump cooling building	" "	0 0		0 0	0 0
1.7.3.3.5	7	Cryo - Warm Compressor	" "	5 3600	720 m^2	5 2090	5 3600
1.7.3.3.5	8	Cryo - Surface Cold box	" "	5 3000	600 m^2	5 2905	5 3000
1.7.3.3.6	9	Control Rooms	" "	5 500	100 m^2	0 0	5 500
1.7.3.3.6	10	Control Room	" "	0 0		0 0	0 0
1.7.3.3.7	11	Workshop	" "	2 900	----------	4 4192	2 900
1.7.3.3.8	12	Site Access building	" "	5 500	100 m^2	4 280	5 500
1.7.3.3.9	13	Shaft Access	" "	5 3300	660 m^2	5 4355	5 3300
1.7.3.3.10	14	Laser building	" "	0 0		0 0	0 0
1.7.3.3.10	15	Rad building	" "	0 0		0 0	0 0
1.7.3.3.10	16	Gaz building	" "	0 0	Outdoor structure /shaft	0 0	0 0
1.7.3.3.10	4	Underground galleries	# Tot. Length	5 750	----------	5 600	5 600
1.7.3.3.10	5	Platform tank helium	# Tot. surface	5 5000	1,000 m^2	5 5000	5 5000

Conventional Facilities Supporting Documentation for the ILC Reference Design Report
ILC-NOTE-2007-019, May 2007, Rev. 0

5,550 m^2 /shaft + 450 m^2 /workshop
+ ~4,000 m^2 for RF Cluster Building

Cost Impact on Civil in Asian Sample Site

CFS Cost Feature

Denotes Site Independent costed by another region.
Regional monetary unit used
Manhours supplied for all In-House Engineering K units (total manhours /1000
All values are in K units (Monetary value /1000)

				A5 Main Linac	Total
				Asian	
1.7			Conventional Facilities		
1.7.1			Civil Engineering		
	1.7.1.1		Engineering, study work and documentation		
		1.7.1.1.1	In-house Engineering (man-hour)		
		1.7.1.1.2	Outsourced Consultancy Services		
	1.7.1.2		Underground Facilities		
		1.7.1.2.1	Shafts **(Sloped tunnels)**		
		1.7.1.2.2	Tunnels		
		1.7.1.2.3	Halls		
		1.7.1.2.4	Caverns		
		1.7.1.4.5	Miscellaneous works		
	1.7.1.3		Surface Structures		
		1.7.1.3.1	Central Lab Buildings		
		1.7.1.3.2	Detector Assembly Buildings		
		1.7.1.3.3	Office Buildings		
		1.7.1.3.4	Service Buildings		
		1.7.1.3.5	Cryo- Equipment Buildings		
		1.7.1.3.6	Control Buildings		
		1.7.1.3.7	Workshops		
		1.7.1.3.8	Site Access Control Buildings		
		1.7.1.3.9	Shaft Access Buildings		
		1.7.1.3.10	Miscellaneous Buildings		
		1.7.1.3.11	User Facilities		
	1.7.1.4		Site Development		
		1.7.1.4.1	Off-site Site work		
		1.7.1.4.2	Network of Monuments		
		1.7.1.4.3	Construction Support		
		1.7.1.4.4	Site Preparation		
		1.7.1.4.5	Utility Distribution		
		1.7.1.4.6	Road, Sidewalks & Parking Areas		
		1.7.1.4.7	Landscaping		
		1.7.1.4.8	Environmental		
		1.7.1.4.9	Miscellaneous Site Works		
1.7.2			ELECTRICAL		
1.7.7			Safety Equipment		

Cost Impact of RF Cluster Scheme on Civil Construction in Asian Sample Site

(1) 17122 Elimination of ML service tunnel ϕ4.5 m, 22.278 km:	-8.1%
(Elimination of Entire Service Tunnel ϕ4.5 m, 30.019 km: -10.9%)	
(2) 17121 Four additional access tunnels for RF clusters 3.5 m (w) x 3.5 m (H):	+1.2%
(3) 17124 Reduced size of underground caverns:	-0.8% (guess ~half)
(4) 1713 RF cluster building ~ 4,000 m^2 x 10:	+4.0%
(5) 1713 Moved area from underground caverns to surface 1,000 m^2 x 6:	+0.6%
(6) 171431 Decrease of construction support {(1)+(2)+(3)} x 8%:	-0.6%
(7) 171432 Increase of construction support {(4)+(5)} x 4%:	+0.2%
(8) 17144 Increase of site preparation {(4000/3) x10 + 1000 x 6}/0.3 m2:	+0.4%
(9) 1711 Reduction of engineering cost {(1)+(2)+(3)} x 10% {(4)+(5)} x 5%:	-0.5%
	-3.6%
	of total CFS cost

Summary

- Application of RF cluster scheme to Asian Sample Site was studied.
- Roughly 10% of CFS cost will be saved by single tunnel, but 6% will be newly necessary for RF cluster facilities in Asian case.