



# ***GDE ACCELERATOR ADVISORY PANEL REVIEW***

## ***CONVENTIONAL FACILITIES AND SITING GROUP***

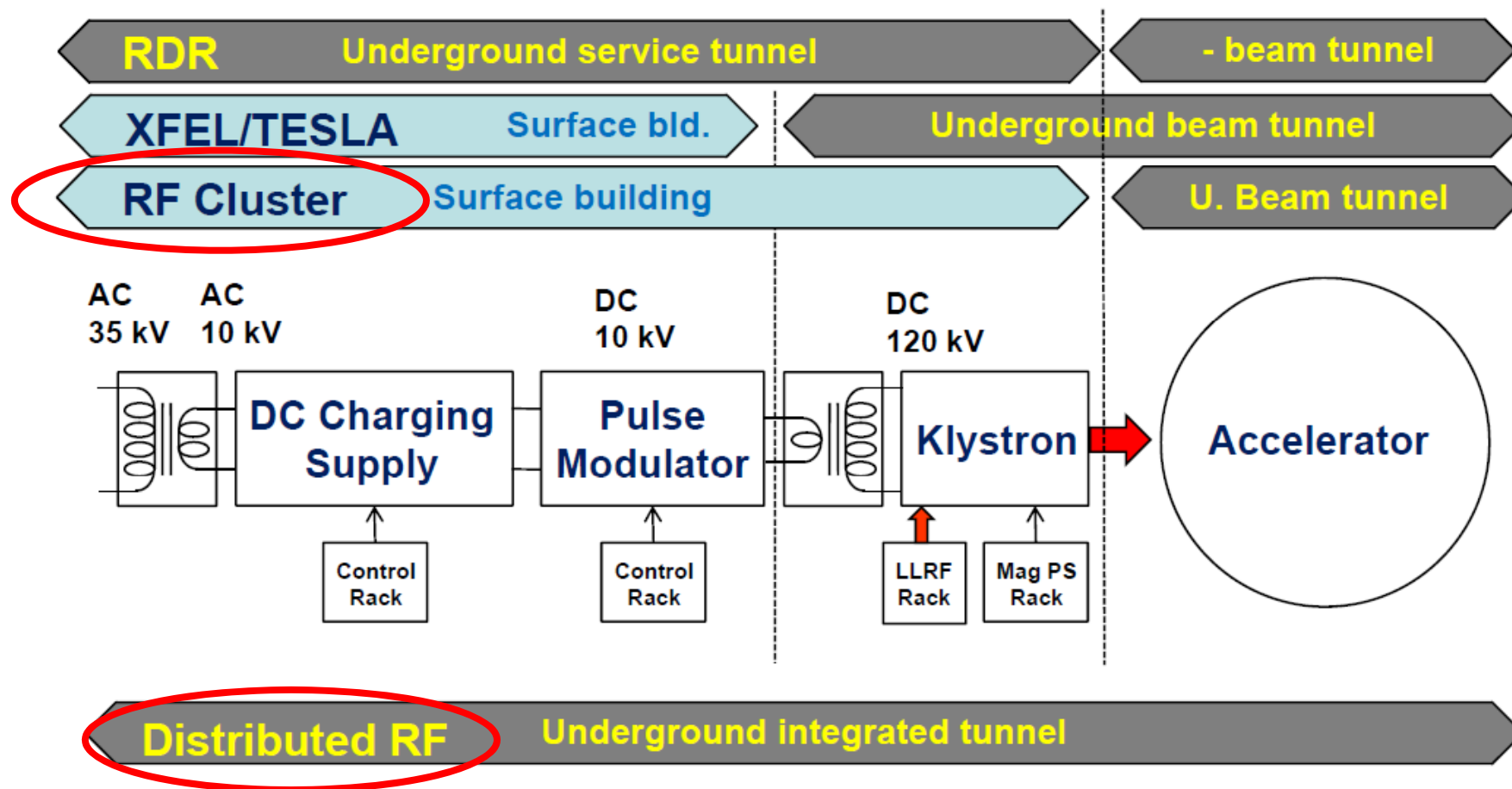
***Single-tunnel scheme studies at KEK  
(RF Cluster and Distributed RF System)***

***Atsushi Enomoto***

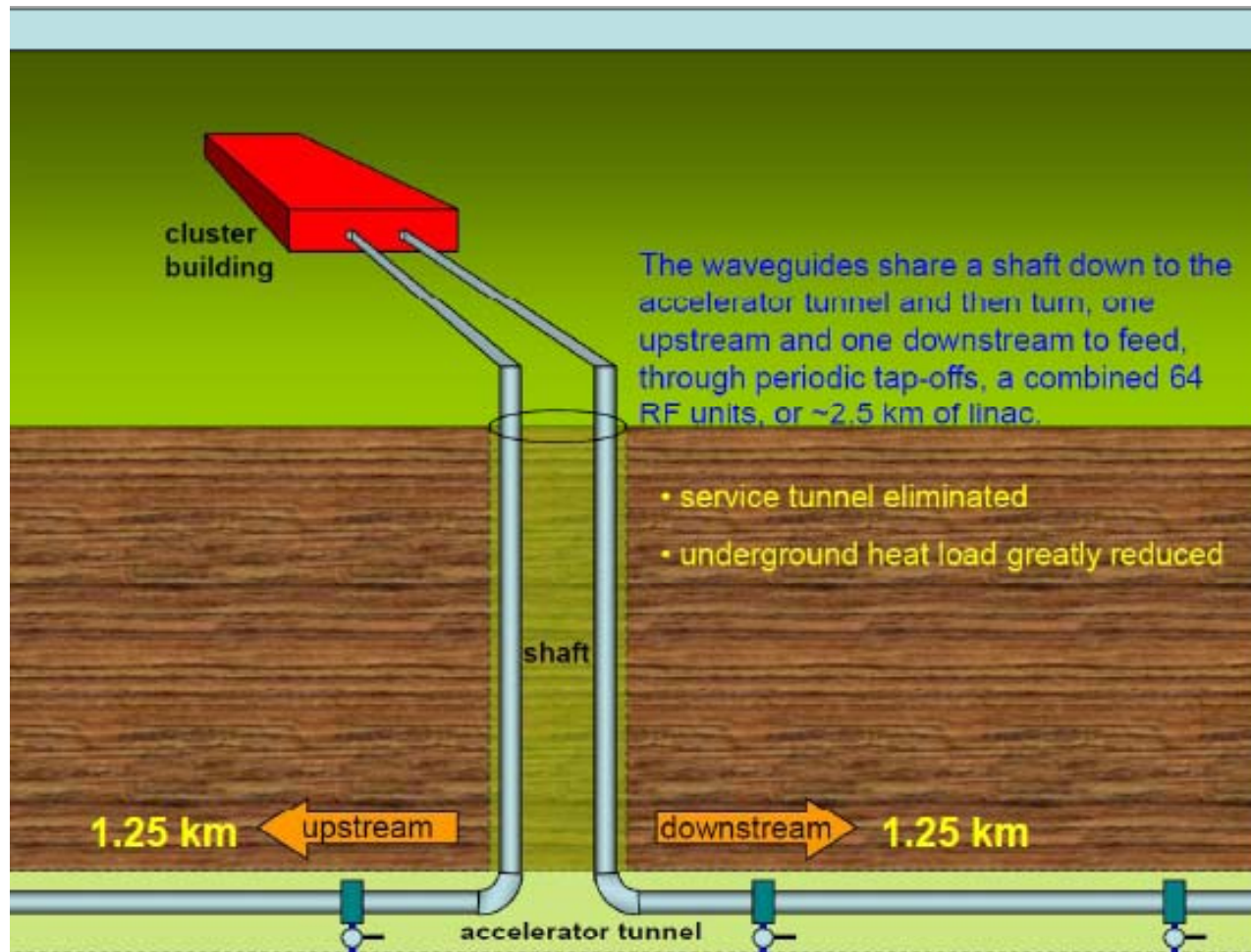
## Contents of this talk

- *Two kinds of single-tunnel schemes applicable for the Asian sample site (deep tunnel).*
- *Pros and cons of these schemes from CFS point of view.*
- *Understanding of degree of cost impacts for the single tunnel scheme.*
- *Plans of further studies.*

## Single-tunnel configurations and power distribution systems

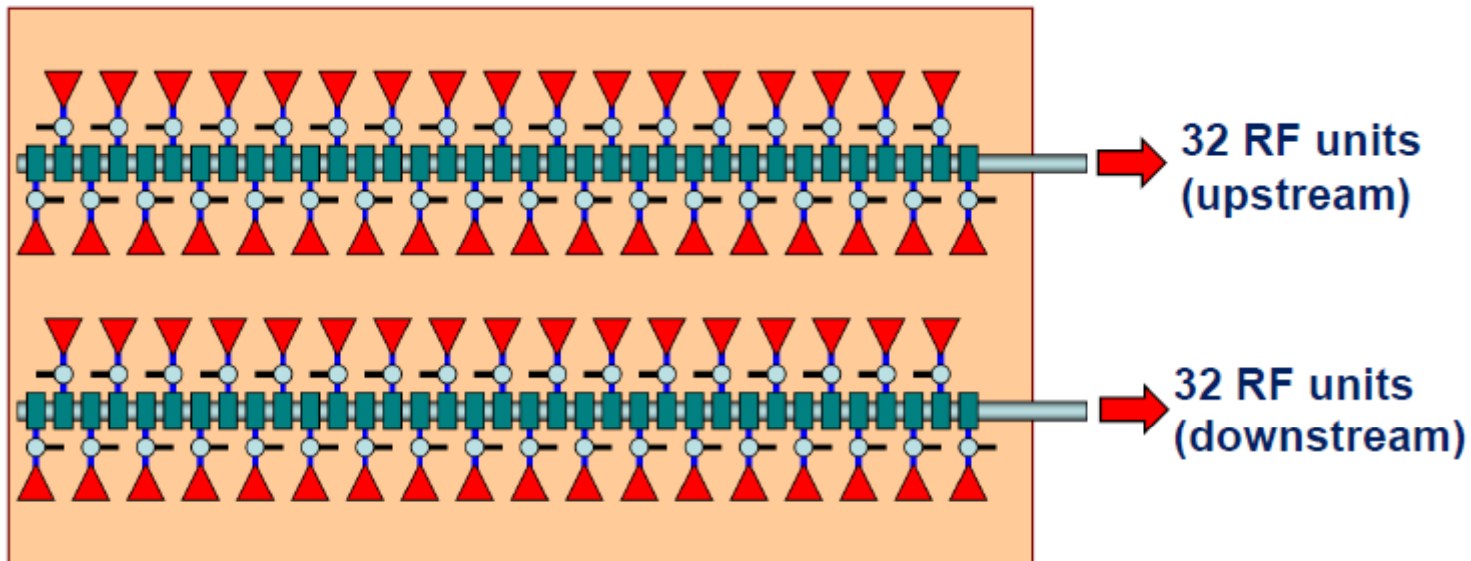


## (1) RF Cluster Scheme



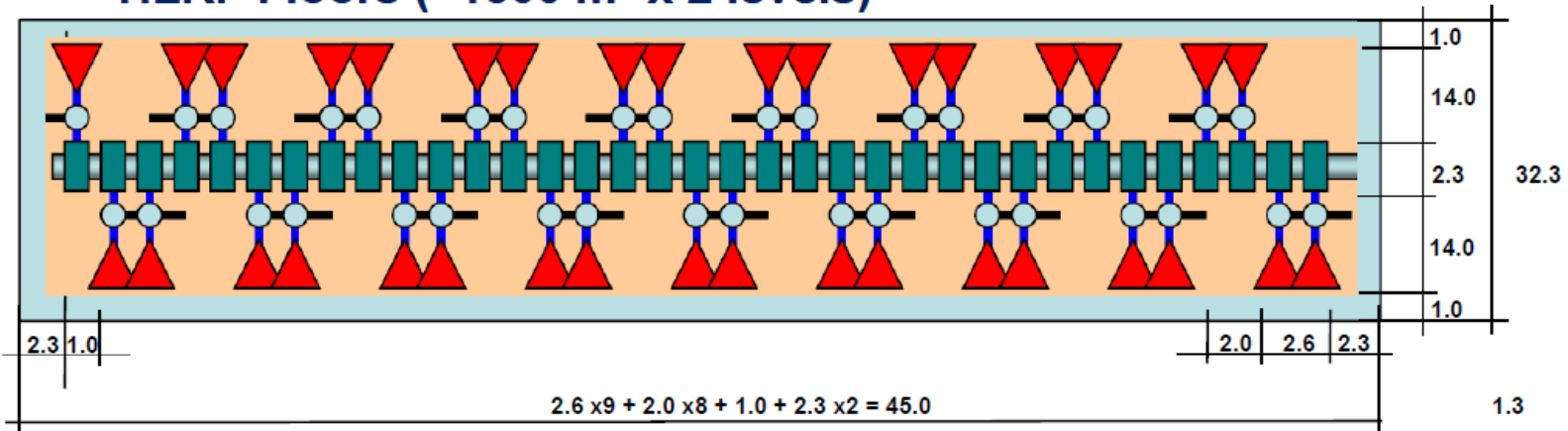
## Surface Station of RF Cluster Scheme

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.

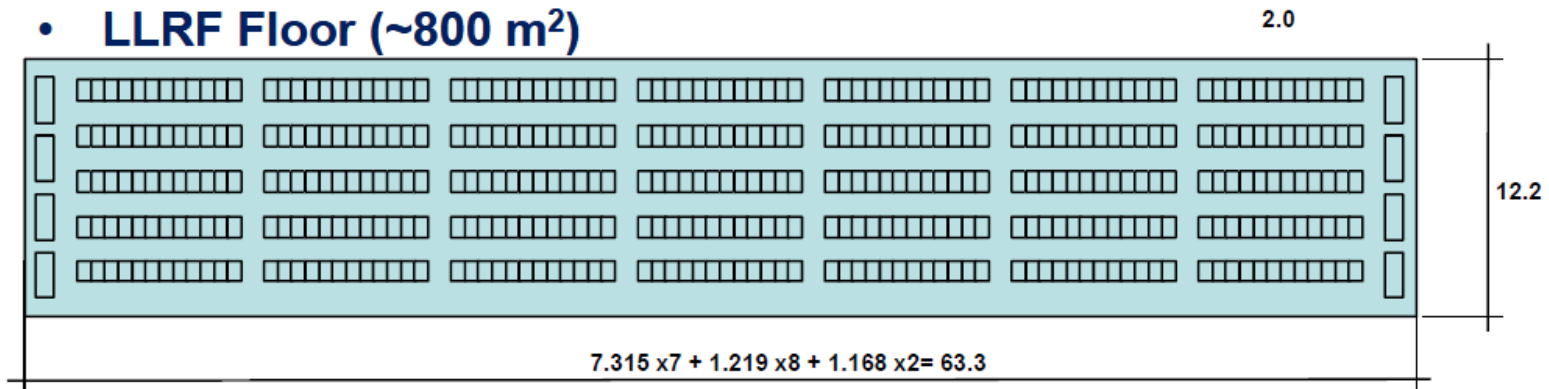


## Estimation of floor size

- HLRF Floors (~1500 m<sup>2</sup> x 2 levels)

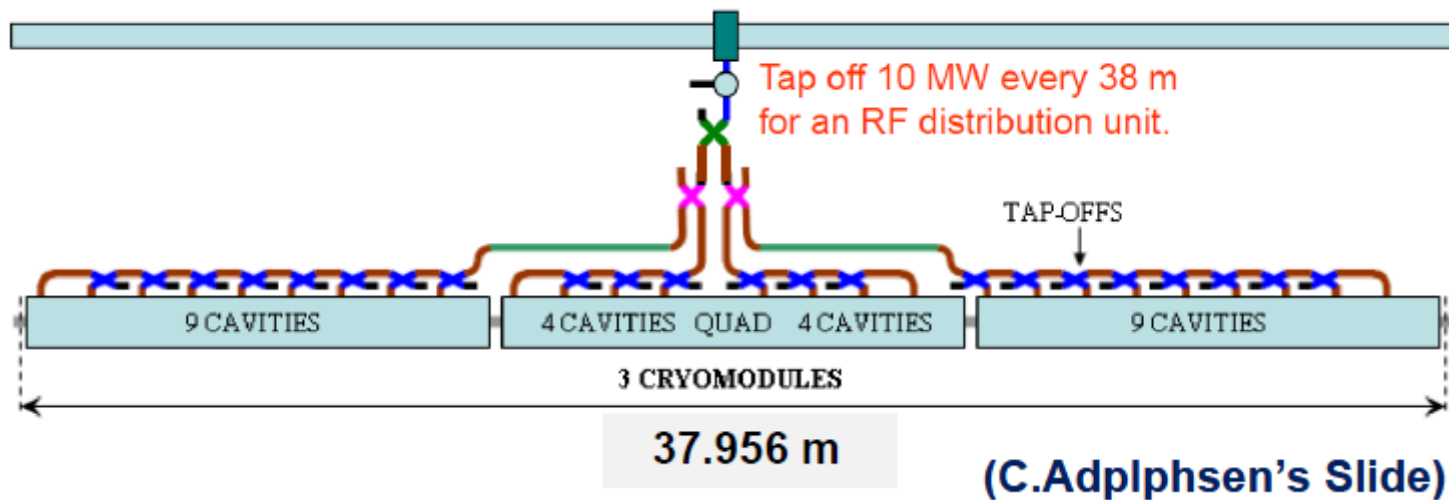


- LLRF Floor (~800 m<sup>2</sup>)



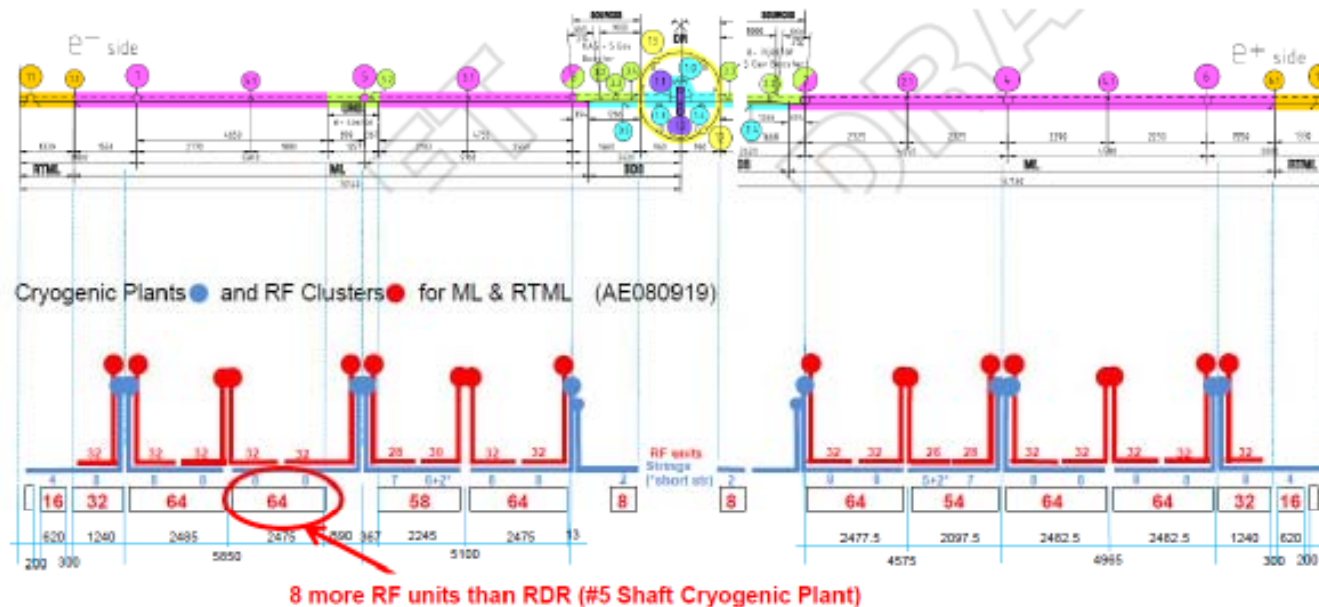
## Local distribution of RF Cluster Scheme

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).

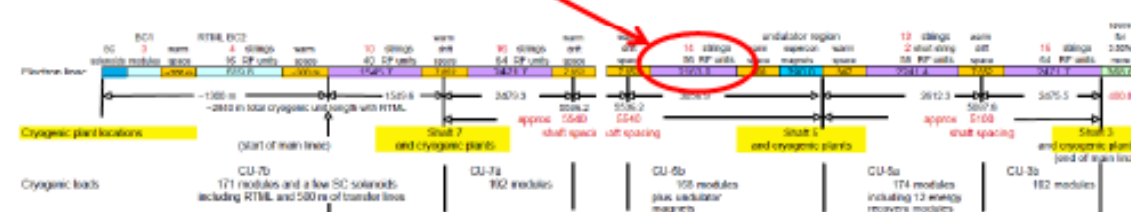


## Schematic layouts of conventional facilities and RF units

ILC Underground Structures Schematic Layout (ILC-CE-1.1649.0016, 05 December 2006)

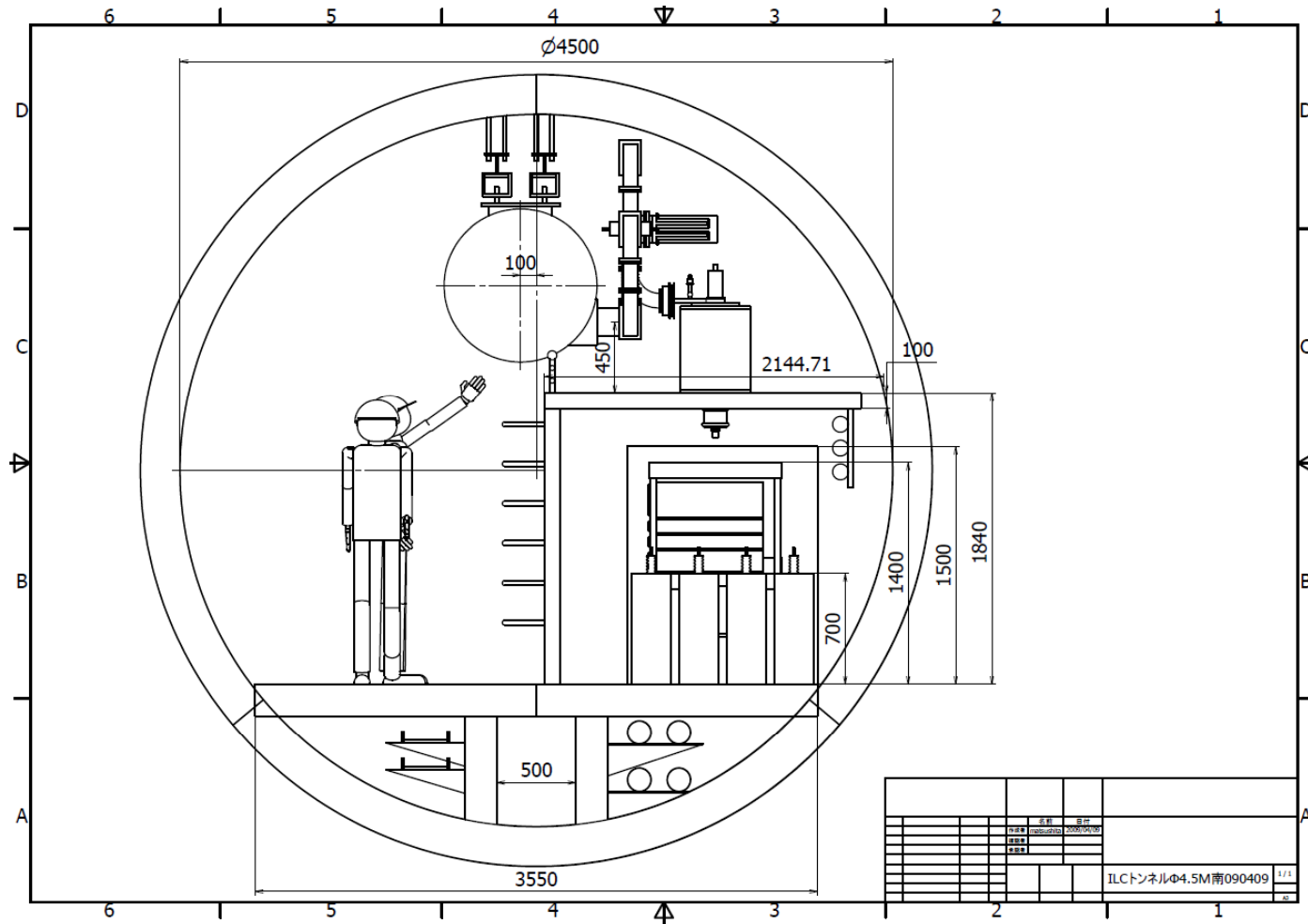


Cryogenic System Configuration (T. Peterson, 20 July 2007)



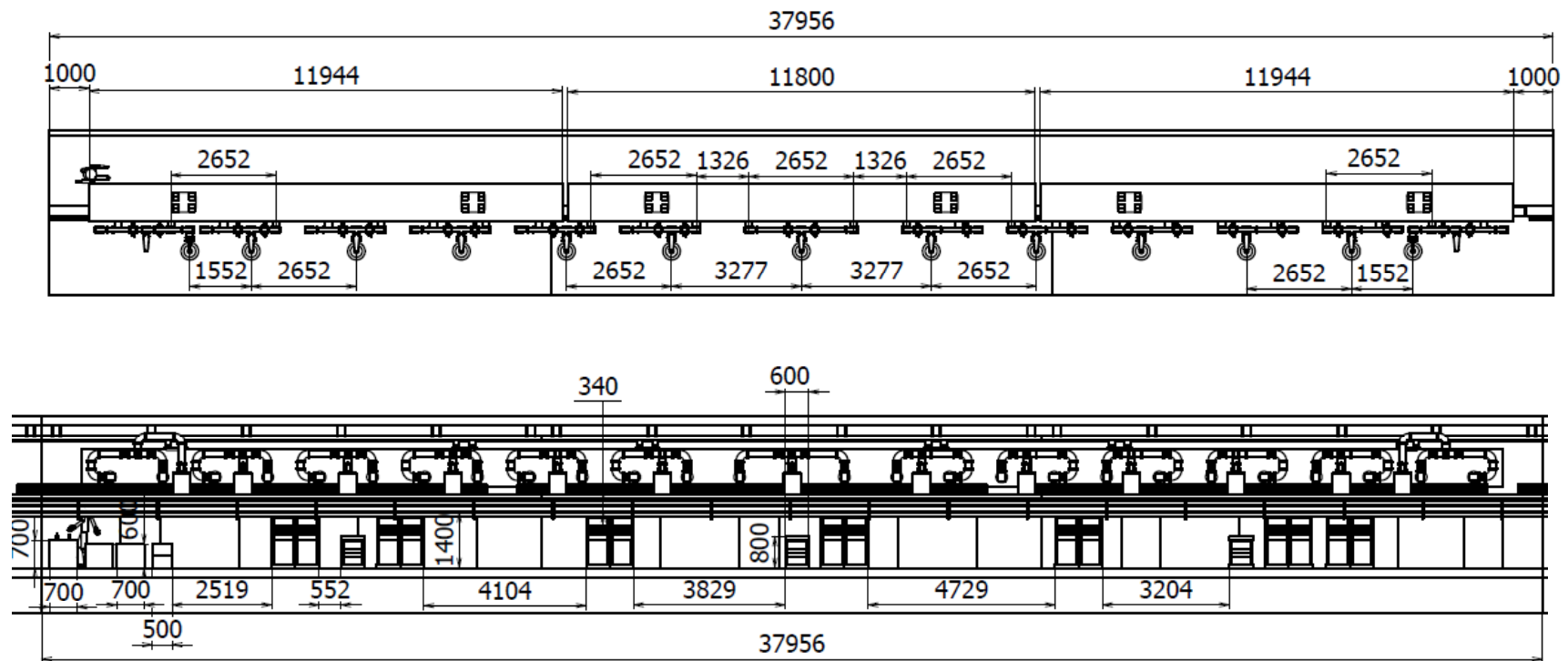


## (2) Distributed RF System (Tunnel view)



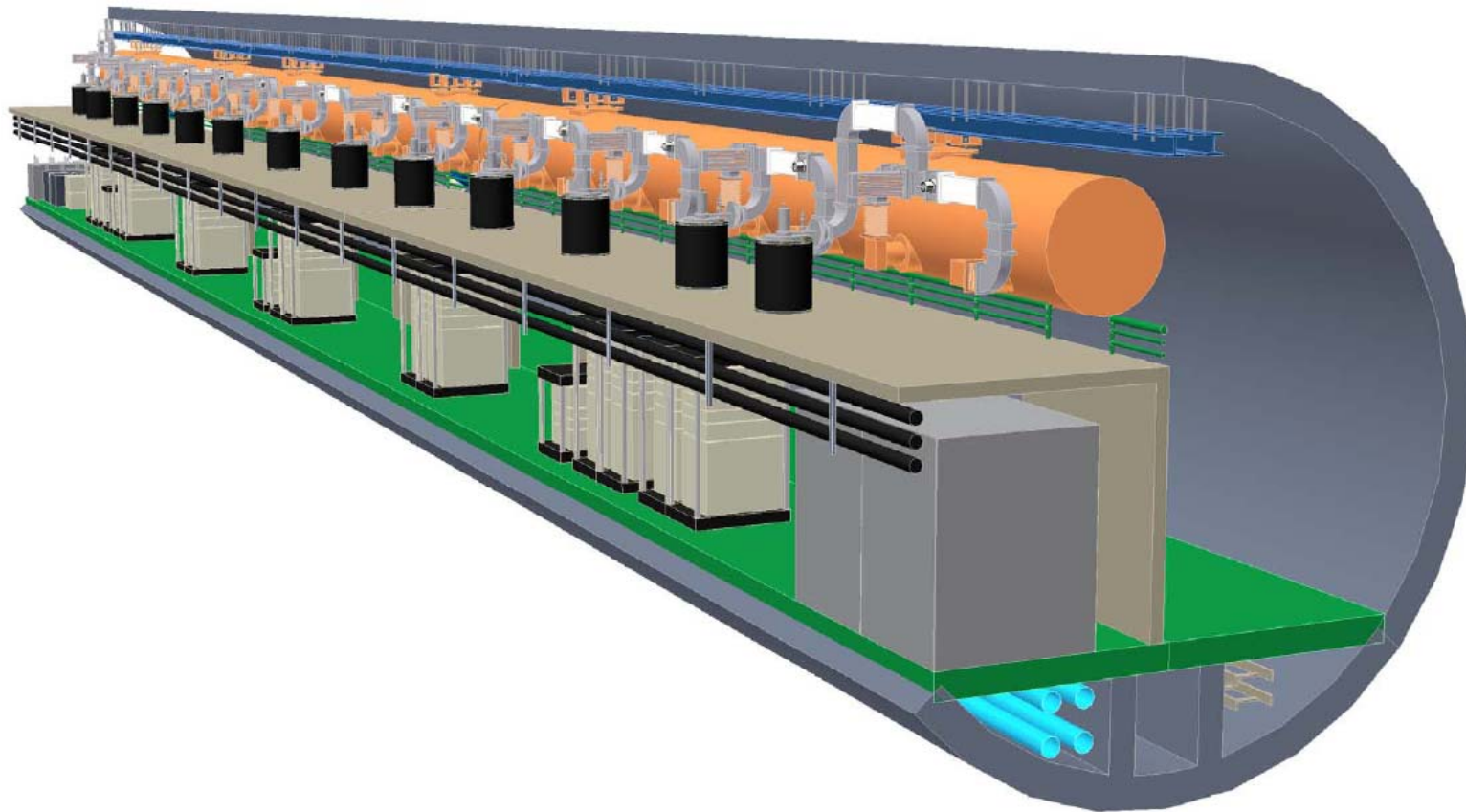


## (2) Distributed RF System (Tunnel view)



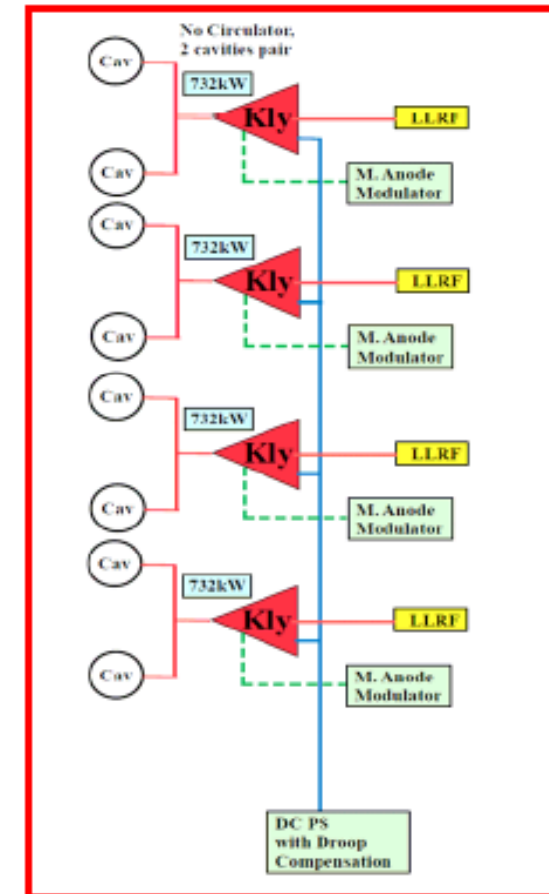
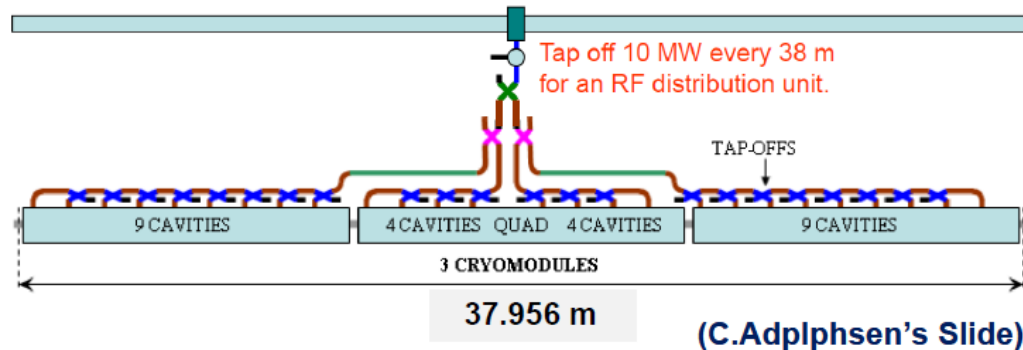


## (2) Distributed RF System (Tunnel view)



## 13 small-size klystrons used instead of one big klystron

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).





## Impacts on Main Linac civil engineering

| Main Linac CF  | RDR  | RF Cluster  | Distributed RF   |
|--|--|---|--|
| <p>Tunnel</p> <p>Penetration<br/>Safety path<br/>Refuge area</p> | <p>φ4.5m, 22.3 km<br/>X2 (double)</p> <p>(φ0.43m, φ0.3m X2) X10m X560<br/>1.2m X2.2m X20m X48<br/>None</p> | <p>φ4.5m, 22.3 km<br/>X 1 (single)</p> <p>None<br/>None<br/>?</p> | <p>φ4.5m, 22.3 km<br/>X 1 (single)</p> <p>None<br/>None<br/>None</p> |
| <p>Access shaft/tunnel</p> <p>(Size and quantity)</p>            | <p>X6</p> <p>7m X6.5m X~1,270m X6</p>  | <p>X10</p> <p>7m X6.5m X~1,270m X6<br/>3.5m X3.5m X~1,270m X4</p> | <p>X</p> <p>7m X6.5m X~1,270m X6</p>                                 |
| <p>Shaft-base cavern</p>   | <p>X6</p> <p>16m X18m X100m</p>  | <p>X6</p> <p>~ half</p>   | <p>X6</p> <p>16m X18m X100m</p>                                      |
| <p>Surface building</p>  | <p>X6</p> <p>4,300m<sup>2</sup> X6</p>   | <p>X10</p> <p>~7,000m<sup>2</sup> X10</p>                         | <p>X6</p> <p>4,300m<sup>2</sup> X6</p>                               |
| <p>Remarks</p>   |  |   |  |



## Preliminary cost estimates

| Main Linac CF               | RDR   | RF Cluster | Distributed RF |
|-----------------------------|-------|------------|----------------|
| 1711<br>Engineering         |       | -1.9       | -2.8           |
| 1712<br>Underground         |       | -26.8      | -27.0          |
| 1713<br>Surface             |       | +14.6      | 0              |
| 1714<br>Site<br>development |       | +2.3       | -2.1           |
| Total                       | 100.0 | 88.2       | 68.1           |
| Remarks                     |       |            |                |



## Cost impact factor (RDR)

TABLE 6.2-2

Distribution of the ILC Value Estimate by area system and common infrastructure, in ILC Units. The estimate for the experimental detectors for particle physics is not included. (The Conventional Facilities estimates have been averaged over the three regional site estimates. )

| Area - M ILC Units    | Total | Components | Conventional Facilities |
|-----------------------|-------|------------|-------------------------|
| Main Linac            | 3,894 | 2,723      | 1,172                   |
| DR                    | 630   | 398        | 231                     |
| RTML                  | 554   | 320        | 234                     |
| e <sup>+</sup> source | 398   | 232        | 166                     |
| BDS                   | 408   | 157        | 252                     |
| Common                | 369   | 229        | 140                     |
| Exp Hall              | 200   | 0          | 200                     |
| e <sup>-</sup> source | 165   | 87         | 78                      |
| Sum                   | 6,618 | 4,146      | 2,472                   |

TABLE 6.2-1

Possible division of responsibilities for the 3 sample sites (ILC Units).

| Region  | Site-Specific | Shared | Total  |
|---|---------------|--------|--------|
| Asia  | 1.75 B        | 4.78 B | 6.53 B |
| Americas  | 1.89 B        | 4.79 B | 6.68 B |
| Europe  | 1.85 B        | 4.79 B | 6.64 B |
| and Average   | 1.83 B        | 4.79 B | 6.62 B |
| plus 14 K person-years of explicit labor<br>or 24 M person-hours 1,700 hours/year |               |        |        |

1 ILC Unit = 1 US 2007\$ (= 0.83 Euro = 117 Yen)

|                    |      |  |  |
|--------------------|------|--|--|
| Total Project Cost | 6.62 |  |  |
| CFS                | 2.47 |  |  |
| ML                 | 1.17 |  |  |
| Civil (Asia)       |      |  |  |

|                    |     |     |     |
|--------------------|-----|-----|-----|
| Total Project Cost | 100 |     |     |
| CFS                | 37  | 100 |     |
| ML                 | 18  | 47  | 100 |
| Civil (Asia)       |     |     |     |



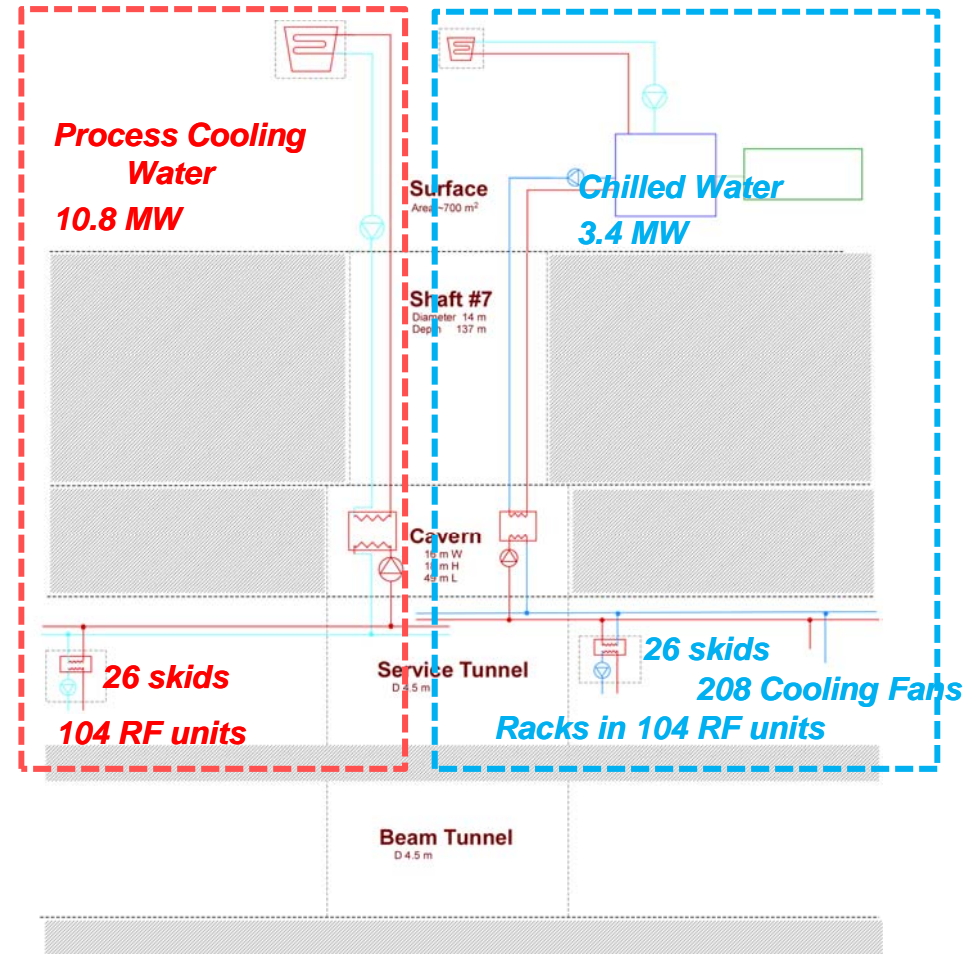
## Impacts on cooling system (heat loads)

Dec 14 2007

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

| MAIN LINAC - ELECTRON & POSITRON  |                  |                |                      |                        |                         |                                 |                                    |                          |
|---|------------------|----------------|----------------------|------------------------|-------------------------|---------------------------------|------------------------------------|--------------------------|
| Components  | Quantity Per 36m | Location       | Total Heat Load (KW) | Average Heat Load (KW) | Heat Load to Water (KW) | Heat Load to Chilled Water (KW) | Power fraction to Tunnel Air (0-1) | Power to Tunnel Air (KW) |
| <b>Non-RF Components</b>  |                  |                |                      |                        |                         |                                 |                                    |                          |
| LCW Skid Pump 1 per 4 rf - Motor/Feeder Loss  | 0.25             | Service Tunnel | 0.60                 | 0.60                   | 0                       | 0                               | 1.00                               | 0.60                     |
| 1/2 R 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                               | 1.00                               | 0.20                     |
| Rack Water Skid   | 0.25             | Service Tunnel | 0.20                 | 0.20                   | 0                       | 0                               | 1.00                               | 1.65                     |
| Lighting Heat Dissipation ~1.3W/sf  |                  | Service Tunnel | 1.65                 | 1.65                   | 0                       | 0                               | 0.25                               | 0.50                     |
| AC Pwr Transformer 34.5-48 kV   | 0.25             | Service Tunnel | 2.00                 | 2.00                   | 1.50                    | 0                               | 1.00                               | 1.00                     |
| Emerg. AC Pwr Transformer 34.5-48 kV  |                  | Service Tunnel | 1.00                 | 1.00                   | 0                       | 0                               | 1.00                               | 1.00                     |
| <b>RF Components</b>  |                  |                |                      |                        |                         |                                 |                                    |                          |
| 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                    | 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                     |
|   | 2/36 m           | Service Tunnel |                      |                        | 0                       |                                 |                                    | 0.0                      |
|   | 1/36 m           | Service Tunnel |                      |                        | 0                       |                                 |                                    | 1.66                     |
| RF Distribution (Attenuators, Loads, Waveguide, Circulators all in series connection) | 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                     | 103.5                   | 11.5                            |                                    | 21.4                     |
| 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   |



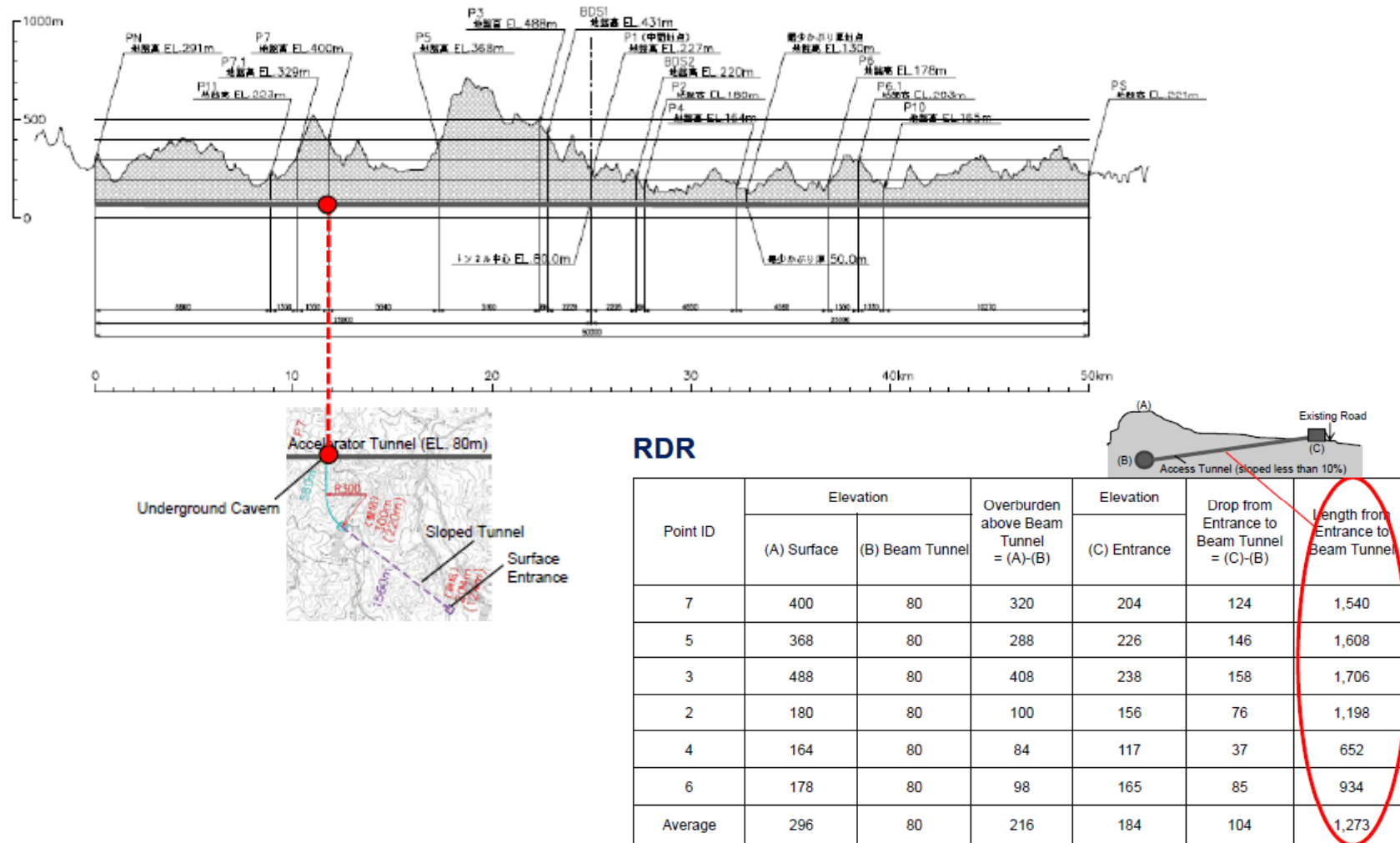
In RF cluster scheme, ~40% of the heat loads remain in the underground.

Area for substation at shaft-base cavern and RF skids will be reduced in capacity but not eliminated.





## Site specific issues for Asian sample site



## Longer transportation of RF (RF cluster)

### Attenuation Of RF Through Cylindrical Waveguides

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

$\alpha$ : attenuation constant (neper/m)  
 $R_s$ : skin resistance ( $\Omega$ )  
 $Z_0$ : intrinsic impedance  $\sim 377 \Omega$   
 $k_0$ : propagation constant in free space  
 $k_c = \chi_{01}/a$ : cut-off propagation constant  
 $\chi_{01} = 3.832$  for TE<sub>01</sub> mode  
 $2a$ : inner diameter of cylindrical waveguide

Cu

$$\rho_{20} = 1.72 \times 10^{-8} \Omega m$$

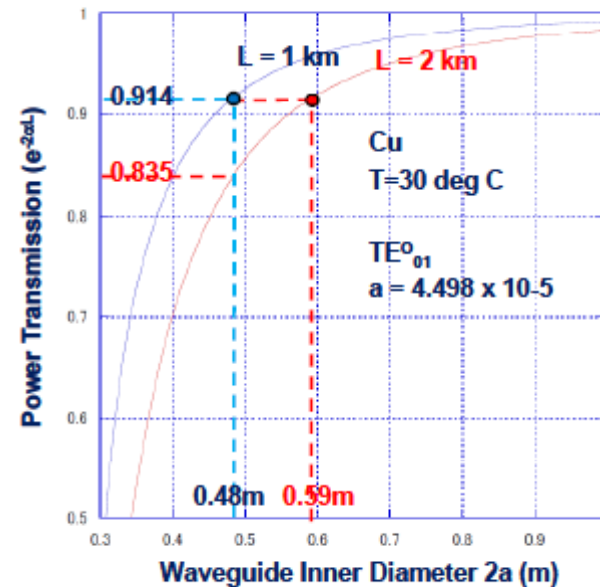
$$\rho_{0-100} = 4.3 \times 10^{-3} / \text{deg}$$

TE<sub>01</sub><sup>o</sup>

$$\alpha = 4.498 \times 10^{-5} \text{ (} 2a = 0.48 \text{ m)}$$

$$\alpha = 2.233 \times 10^{-5} \text{ (} 2a = 0.59 \text{ m)}$$

@T=30 deg C



Waveguides which are  $\sim 1$  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.

## Longer transportaion of RF (RF cluster)

### 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)

$\alpha$ : 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<sup>2</sup>K)

$D_e$ : outer diameter of waveguide (m)

$\theta_{se}$ : temperature of surface on waveguide (deg C)

$\theta_a$ : temperature of ambient air around waveguide (deg C)

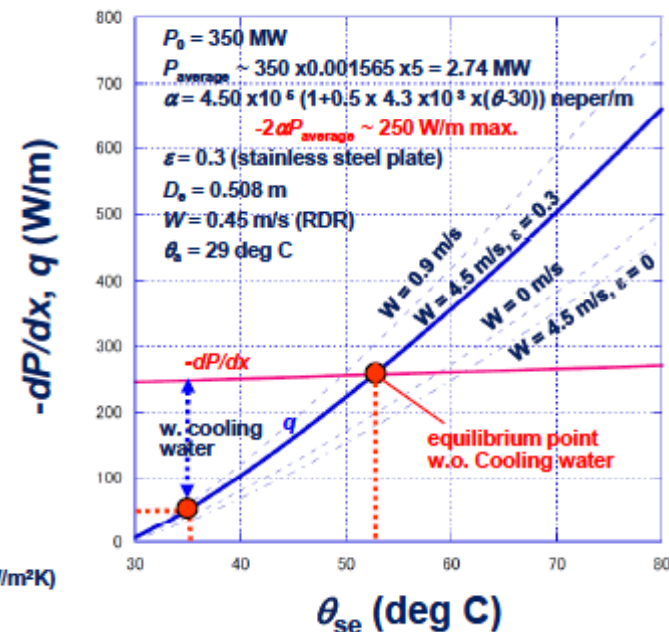
$\varepsilon$ : radiation efficiency

$\sigma$ : Stefan-Boltzmann constant  $5.67 \times 10^{-8}$  (Wm<sup>-2</sup>K<sup>-4</sup>)

$T_{se}$ : 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)




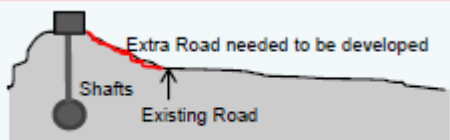
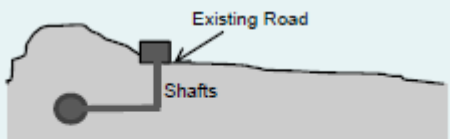
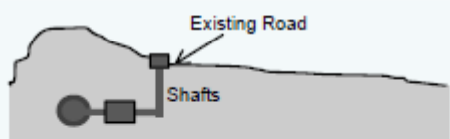
Waveguides radiate ~250 W/m max. or ~9



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.

## Plans of further studies

**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) |  |

 Beam Tunnel   
  RF Cluster

## Summary of this talk

- *As a study of minimum machine, two kinds of single-tunnel schemes were investigated in order to apply them for the Asian sample site (deep tunnel).*
- *Though both of two are considered to be applicable, from a civil-engineering point of view, “Distributed RF Scheme” seems more suitable for the Asian site.*
- *Further studies should cover overall CF designs such as cooling and safety issues.*