Contents

Chapter 13

Conventional Facilities and Siting

13.1 Introduction

In the RDR a generic CFS design was developed and used in each of three regional sample sites. This resulted in very similar overall layouts using a twin Main Linac tunnel configuration and common designs for supporting mechanical and electrical utility systems. The current technical design reflects several changes with respect to the RDR design. Most importantly, the conventional facility designs in each region are tailored to accommodate local site conditions and have generated some differences among the regional designs. In addition, the designs have incorporated the results of several value engineering studies, tunnel configuration studies, detailed site specific designs for conventional facilities and mechanical and electrical utility systems. Most notable is the introduction of the Klystron Cluster high level RF system (KCS) for the Americas and European regions and the Distributed Klystron high level RF system (DKS) for the Asian region.

The designs that have been developed for the Americas and European regions are very similar. The Americas design has been based on the Fermilab site in north-eastern Illinois. The European design has been developed for a site near the CERN Laboratory in Switzerland. A preliminary evaluation of a second site near the Joint Institute for Nuclear Research in Dubna, Russia has also been performed. In all cases a single Main Linac (ML) tunnel is used with the KCS, which places all of the klystrons and related equipment in surface buildings at the tops of vertical shafts. From these klystron buildings waveguide distributes the microwave power through the vertical shafts and ML tunnel. In both regions, tunnel boring machines (TBMs) are used for the bulk of the underground construction. For enlarged tunnel sections and underground halls the drill and blast excavation method is used. One distinction between the Americas and European designs is the approach to ventilation and smoke control. European regulations require large supply and return air ducts to provide conditioned air to all parts of the tunnel. Smaller ducts are used in the Americas design and are cast into the tunnel invert. The Interaction Region (IR) Hall designs are also quite similar in both the Americas and European regions with respect to floor layout and detector assembly. In both cases, surface buildings are used to assemble large pieces of both detectors which are then lowered into the detector hall through vertical shafts similar to the CMS detector assembly scheme used at CERN.

Japan has identified two candidate sites. One is located in the Kitakami Mountains in Tohoku and the other is in the Sefuri Mountains in Kyushu. Both sites are in mountainous areas and access considerations preclude the use of vertical shafts. As a result, inclined horizontal tunnels are used for access to the main tunnels and IR hall. There are some surface buildings at the entrance to the access tunnels, but surface facilities are minimized to limit environmental impact. The preferred means for underground construction in Japan is the New Austrian Tunneling Method (NATM) which is primarily a drill and blast method. As a result the ML tunnel cross sectional dimensions can be larger than the circular cross sections usedin the Americas and Europe. This additional tunnel width provides the opportunity to divide the Main Linac tunnel into two compartments separated by a center shielding wall. The accelerator components are installed on one side of the wall with the klystrons, power supplies and other support services located on the other side of the dividing wall. This arrangement has the advantage of allowing personnel to occupy the service side of the ML tunnel during beam-on conditions to provide maintenance capabilities while continuing beam operations. Japan has a great deal of experience in mountain construction of auto, rail and hydro-electric power tunnels. Detector construction and assembly methods will be very different between a mountain site and one with relatively uniform surface elevations. These factors alone will have a direct impact on the integrated construction, installation and commissioning schedule and possibly overall project cost.

We cannot preclude that other regions or countries may choose to develop candidate sites. These sites, each with their own unique features, may also require review and/or adjustment of some technical criteria. A final site selection will have to include a careful analysis of the impact of local conditions with respect to the overall ILC design.

13.2 Overall Layout

Depending on the geology, the Main Linac either has a single tunnel (European or American) or a wide tunnel with parallel galleries, one containing the beamlines and one accessible with equipment. The Main Linac Beam tunnel also houses the Ring to Main Linac (RTML) 5 GeV transport line supported from the ceiling and positioned towards the center of the tunnel. The Damping Ring has a single tunnel large enough to contain an electron ring, a positron ring and a possible future second Position ring.

The Central Region area, from the IR hall to the ends of the Main Linacs, has both a beam tunnel and a service tunnel. The Beam Tunnel houses multiple beam lines including the e^- and e^+ sources, the Beam Delivery System (BDS), the RTML and beamlines that transport beam to the various aborts and dumps. The central Region tunnels also include the short segments that route beam lines to and from the Damping Ring. All tunnels have been sized to fit the installed equipment, transport or stage a replacement component and allow for personnel to egress around the staged piece of equipment. The beam and service tunnel are widened as needed to maintain the same aisle width as in the Main Linac.

The service and beam tunnels are separated by sufficient rock to provide structural stability and radiation shielding for workers in the service tunnel while the accelerator is operating. Penetrations between tunnels have been sized and configured to provide the required radiation shielding and passageways between the tunnels are “V” shaped.

The large cavern at the Interaction Region is sized to support two detectors in a “Push Pull” configuration. Each detector garage area is connected to the Beam Tunnel, and to the egress elevator through a passageway.

13.3 Common design criteria

While local conditions have a large effect on the ultimate design solution for any selected site, there are some aspects of the design criteria that remain the same. The configuration of the beamlines from the Sources through the Damping Ring, RTML, Main Linacs and Beam Delivery System (BDS) to the interaction point and the dumps is unlikely to be substantially modified to suit a specific site limitation. However the design and construction of the enclosures and tunnels that house the beam lines and related equipment must conform to local geologic and ground conditions. The arrangement and operational requirements for the IR Hall and detectors remain the same regardless of the site location. The ILC will have two independent detectors that will alternate data taking at a single interaction point. As such, each detector will be constructed on a moveable platform which must have the capability to accurately move each detector into and out of the interaction point as efficiently as possible.

While the KCS and DKS differ in configuration and equipment layout, the electrical power and cooling systems are respectively very similar, though local conditions and climate will have a direct influence on their design.

13.4 General site requirements

The site must accommodate the initial 31 km overall length as well as the upgrade to 50 km length. The site must also be able to accommodate the area adjacent to the IR for the Damping Rings. Requirements for tunnel access, support equipment and surface buildings may vary between sites but must be included.

Alignment and stability of the working components of the machine is very important for reliable operation of the accelerator. Even more critical is the stability of the IR floor. Two detectors, with respective weights of approximately 15 kt and 10 kt, built on concrete platforms each weighing approximately 2 kt will be regularly moved in and out of the interaction point for data taking. The geology at any proposed site must be able to accommodate these movements and allow the repositioning of these detectors without unsatisfactory deflection or settlement over time. Structural solutions to provide the necessary support will vary among sites. Site with very poor geologic conditions may not be able to provide a viable solution.

Electrical power requirements are substantial. Operation at 500 GeV (1 TeV) will require approximately 161 MW (285 MW) of electrical power respectively. These power requirements are almost certainly a significant addition to any existing local electrical grid power capability. In addition a reliable and ample water source for process cooling will be needed.

Suitable access will be needed during both the construction and operational phases. During the construction phase, a great deal of excavated material will be removed. Trucking routes and deposit locations will need to be identified. During the installation of the machine components, roadway access is likely to be the main delivery option and roads to the site must be able to accommodate both the length and weight requirements of the various components. Rail, air and/or seaport access may be required for various components.

13.5 Asian region (Mountain topography)

13.5.1 Siting studies

13.5.1.1 Location of Asian sample sites

The Asian region currently has two candidate sites, both in Japan, which were selected after several years of study:

- Kitakami site: located in Iwate prefecture (Tohoku district).
- Sefuri site: located in Fukuoka & Saga prefecture (Kyushu district).

They are favoured because of their geographical and geological characteristics, as well as the strong support of the local government and residents. The common geographical and geological features of the two sites include:

- Although mountainous, the region is not particularly steep.
- Location in bedrock suitable for construction of a 31 km accelerator tunnel and a large IR hall cavern.
- Extendability to 50 km tunnel length in the future.
- Little ground vibration to affect the stability of the beams.
- No active faults near the tunnel so no nearby danger of earthquakes.
- No man-made vibration source nearby.

Additional favourable chracteristics include: stable source of 300 MW electric power, adequate cooling water supply, possibility for adequate groundwater treatment, suitable climate and access capability, and available of infrastructure for construction and delivery vehicles.

13.5.1.2 Land features

Although the sites are located in mountainous regions largely covered by forest, the base of the mountains is more gently sloping terrain, sparsely populated with small clusters of houses and comparatively small-scale agriculture and dairy farms. Access to the underground tunnels would be located in this more accessible terrain. These areas would also serve as a base for construction, and provide access to the experimental facility after completion. Basic infrastructure, such as required roads and electric power lines, already exists.

13.5.1.3 Climate

The Kitakami site has a slightly cold climate where the air mean temperature in the coldest month (January) is −4.8 °C. The mean air temperature in the warmest month (August) is +28.8 °C. The mean annual rainfall is 1,318 mm. The Sefuri site has a mild climate. The mean air temperature of the coldest month (January) is +3.0 °C. The mean air temperature of the warmest month (August) is +32.1 °C. The mean annual rainfall is 1,612 mm. In both sites, there is occasional snow in January and February, but the snowfall is light.

The Kitakami site is located in the Tohoku district which was hit by a massive earthquake in March, 2011. Although this area is not far from the location of the earthquake, there was little damage. The Sefuti site is located in the Kyushu district; although this is hit by typhoons every year almost no damage is caused.

13.5.1.4 Geology and tunnel structures

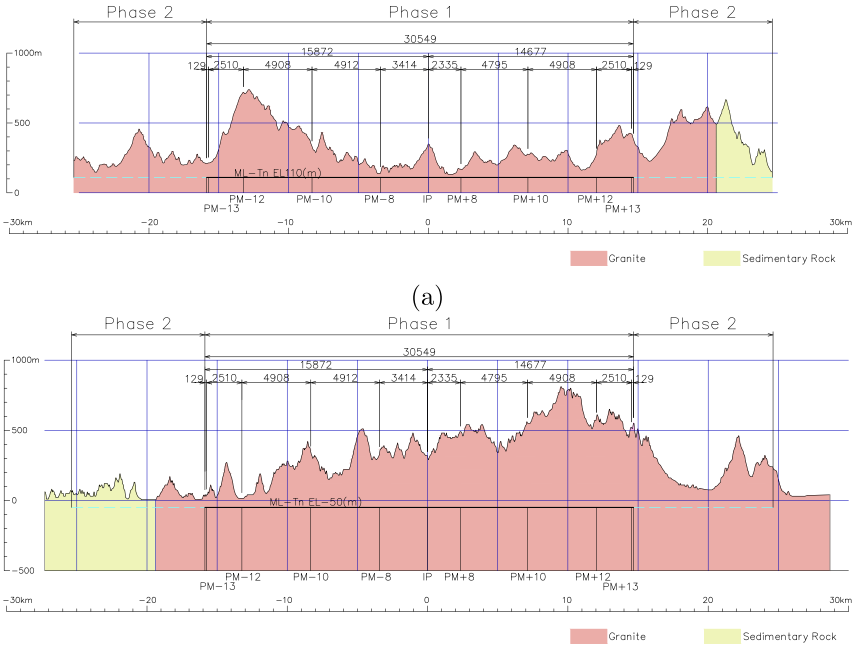
The 31 km ML tunnel and various caverns would be built in the hard granite bedrock. However, if the tunnel is extended to 50 km, at both sites both ends would extend beyond the granite into sedimentary rock. However, the sedimentary rock should also provide a stable base for tunnel construction.

The ML tunnel is located at a depth of between 50 m and 400 m. Access is through a sloped tunnel with a grade of no more than 10% for the ML tunnel and 7% for the IR hall.

The ML tunnel has a dual-highway shape ('Kamaboko'). Rock bolt reinforcement is not usually required in stable granite, but may be required in any cross-sectional extensions. The tunnel interior is lined with concrete to provide waterproofing, so the external groundwater can be processed by normal drainage. The access tunnel does not need to be waterproof and the interior is sprayed concrete. The cavern for the experimental hall is sufficiently large that rock anchor or rock bolt reinforcement is required.

13.5.1.5 Power availability

Both sites have sufficient electric power to meet requirements for the ILC. Kitakami has a 275 kV line and Sefuri 345 kV. Electric power stability should be adequate for accelerator operation.



(a)

(b)

Figure 13.1: (a) Longitudinal section of Kitakami site geology. (b) Longitudinal section of Sefuri site geology.

13.5.1.6 Construction methods

The ML tunnel is 11.0 m wide and 5.5 m high and is excavated by drill and blast using the New Austrian Tunneling method (NATM). After construction, the tunnel is divided into two parallel galleries by a concrete wall in the center. The wall serves as a radiation shield to allow access to the service gallery while the beam is in operation on the other side. The access tunnels are also excavated by NATM, except where they penetrate the 10 m to 20 m thick surface soil layer, where steel reinforcement is required. The large cavern for the IR hall is excavated from the top down, starting from a top-heading tunnel connected to the access tunnel in what is called a bench-cut construction method. As the excavation progresses it is reinforced by rock-bolts into the cavern wall.

13.5.2 Civil construction

Because the Japanese sites are deep underground, they differ in several ways from the Americas and European sites.

- The ML RF power is supplied by a Distributed Klystron System (DKS) with the RF sources in the service gallery. The ML tunnel lengths are 11,188 m (electron) and 11,072 m (positron).
- The underground structures are divided into seven areas, each with a maximum span of ± 2.5 km from the access point due to the capacity of the cryogenic plants.
- The sloped access tunnel for the IR hall dictates a different design for the underground enclosures and installation method.
- Some utilities that would usually be on the surface are located in underground caverns.

13.5.2.1 Overall site layout

The overall site layout is shown in Fig. 13.2. The ML length is slightly longer with the DKS because of the choice of a 9-module cryogenic string to allow a future upgrade from 4.5-modules/klystron to 3 modules/klystron. The number of access points is the minimum consistent with cryogenic plant layout (Fig. 13.3).

13.5.2.2 Underground enclosures

The sizes and volumes of the underground enclosures are summarized in Table 13.1. The features of the major underground enclosures are described in the following sub sections.

13.5.2.2.1 ML tunnel A comparison of various construction methods indicated that NATM would be the most cost effective for mountainous sites, although the excavation speed is slower ($\sim 100\,\mathrm{m/month}$). This can be mitigated by the fact that NATM allows shorter construction zones so more locations can be excavated in parallel.

The cross-sectional layout of the ML tunnel with center wall is shown in Fig. 13.4. The tunnel walls are reinforced by rock bolts. Each gallery has functional zones for equipment installation, survey, conveyance, and human egress. To the right of the

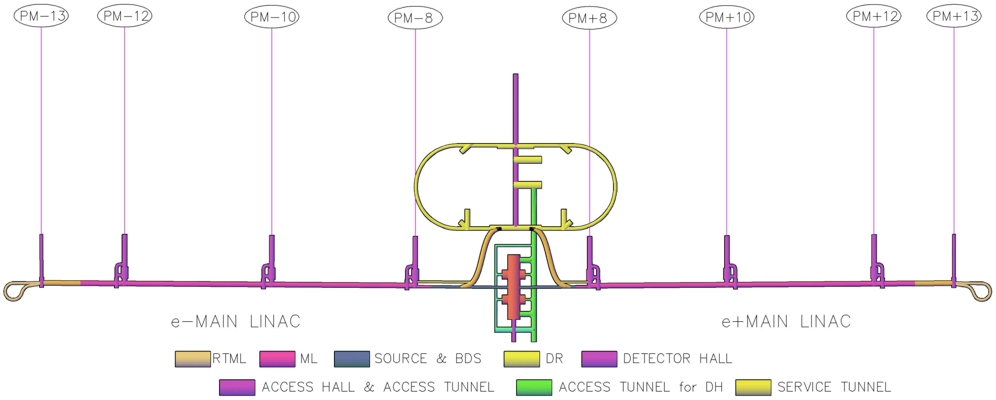


Figure 13.2: Asian region overall site layout.

cryomodules in the ‘beam gallery’, and of the modulators in the ‘service gallery’, is a zone for equipment conveyance and human egress. To the left is working space which provides an alternate egress if the right is blocked. This dictates a minimum tunnel width of 7.5 m. Water pipes are installed in the lower part of the tunnel and electric power lines are installed in (shielded) cable racks on the ceiling.

At its base the center wall is 3.5 m thick to provide radiation shielding and the upper side thickness is *m.(**Ed:** *missing VALUE)* At intervals of 12 (**Ed:** *or 8 or 4?)* RF units, there is a connection passage between the beam and service galleries, which can be used for evacuation in case of emergency. At each connection, the center wall thickness is increased by 2 m in the downbeam direction to provide more shielding. To allow efficient excavation, the tunnel height must be at least 5 m high, based on the passage of standard excavation machines (∼3.5 m high), plus the sliding-form for the concrete lining (∼1 m thick), plus the concrete liner 30 cm thick. The tunnel floor is 40 cm thick. The ML tunnel is excavated basically along a geoid plane, with no more than 0.8% slope to minimize the access tunnel length. (**Ed:** *meaning unclear)* The total length and excavation volume of the nine access tunnels are *** km and ***m^3 respectively, (**Ed:** *missing VALUES)* averaged between the two sites.

The inflow water data must be confirmed by geologic studies before construction, but it is expected to be less than ∼1 t /min /km. Previous constructions have shown that grout can only withstand ∼1 l/min/m at 100 m depth underground. The inflow

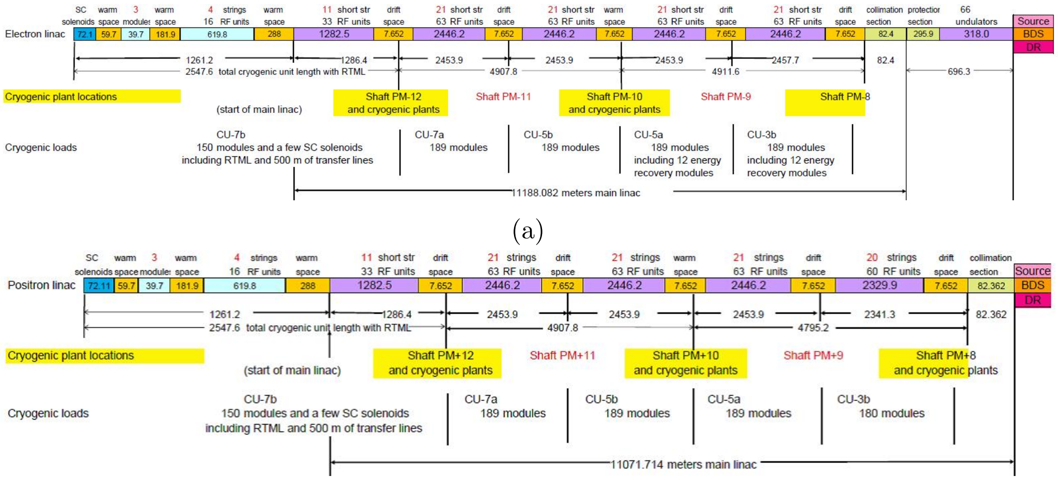


Figure 13.3: ML access hall configuration.**(Ed:** *Figure quality poor - text unreadable)*

water will be completely isolated by the concrete liner and drained to a ditch, sized assuming the inflow water for 5 km is gathered to one access point.

13.5.2.2.2 Access halls (AH) An“access hall” in the Asian site corresponds functionally to a “shaft-base cavern” at the other sites. The six halls for the ML/RTML/BDS areas are located alongside the main underground tunnel. They provide an entrance to the tunnel as well as a local center for electricity, air, cooling water, and liquid He infrastructure. Each AH includes:

- An electrical substation with two 30 MW 66 kV/6.6 kV transformers, an incoming panel, and a distribution panel for cryogenics, accelerator supplies, and service equipment.
- A mechanical station with the second loop heat exchangers with pumps which isolate it from the first loop. This handles the water pressure due to the height difference from the surface.
- A liquid He cryogenic station with 4 K cold boxes with dewars, cold compressors, 2 K cold boxes, and He distribution system.
- A warm compressor whose location must take into account its vibration and noise effects.

Table 13.1: Asian site main underground enclosures

Source area	Leng. Qty (m)	Vol. Qty (m^3)	% Length	% Volume
e^- source (Beam)	2,220.95	84,047.41	5.7%	4.1%
e^- source (Service)	2,035.55	44,570.42	5.2%	2.2%
e^+ source (Beam)	1,126.29	42,622.21	2.9%	2.1%
e^+ source (Service)	987.24	21,616.64	2.5%	1.1%
Damping Ring	3,238.65	120,352.66	8.3%	5.9%
RTML	3,105.20	190,592.48	7.9%	9.4%
Main Linac	22,259.80	1,396,245.70	56.8%	68.8%
BDS (Beam)	2,236.77	84,645.92	5.7%	4.2%
BDS (Service)	2,005.02	43,901.85	5.1%	2.2%
TOTAL	39,215.46	2,028,595.28	100.0%	100.0%

13.5.2.2.3 IR hall (**Ed:** *Missing section)*

Refer to Fig. 13.6

13.5.2.3 Underground access

Sloped tunnels provide access to the underground facilities. There are at least 6 ML access tunnels, plus an additional tunnel in the central region if the topographical conditions allow it.(**Ed:** *Check number of access tunnels!)* A great advantage is that vehicles can be used to transport people and equipment. A disadvantage is the long distances involved which affect the size of cooling/ventilation pipes and pumps; an alternative option is to use small-bore vertical shafts, which can be excavated by a boring machine.

There are two sizes of access tunnels (Fig. 13.7), one to access the six underground areas along the ML, and the other to access the IR hall. The smaller tunnels have a vaulted section with an inner width of 8 m and height of 7.5 m. This is wide enough that two large trucks can pass each other and leave a human escape zone. The height is sufficient to accommodate large pipes for cooling water and air ventilation. The IR hall access tunnel is larger to allow transport of the detector solenoids from the detector assembly building on the surface. Its width is 10.8 m and its height is 7.2 m. Averaged over the two sites the total length and excavation volume of the nine (**Ed:** *7?)* access tunnels are *** km and *** m3 respectively.(**Ed:** *missing VALUES)*

The surface entrances of the access tunnels are located near existing roads. The surface sites around the entrances support construction and are later utilized for

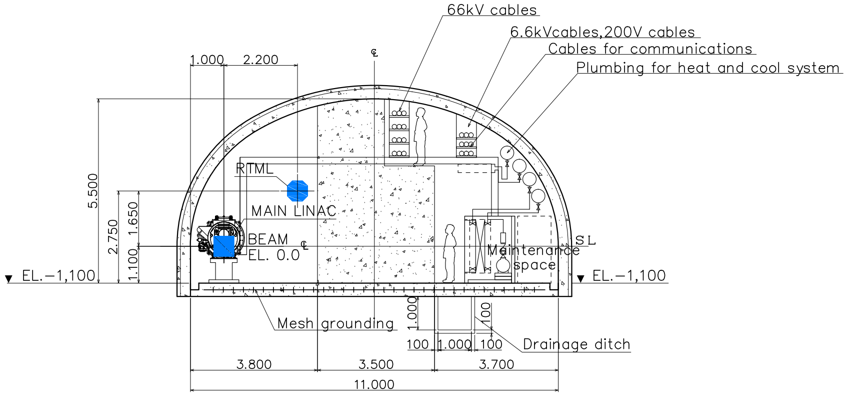


Figure 13.4: Equipment layout in the ML tunnel

facilities such as cooling towers. The tunnel excavation starts from the surface which is assumed to be soil or soft rock down to a depth of ~20 m. The tunnel walls are reinforced by rock bolts and finished with sprayed concrete (so-called "shotcrete") of ∼ 20 cm thick. The tunnel floor is 30 cm thick.

13.5.2.4 Surface facilities

In the mountainous sites, some facilities which would be on the surface elsewhere, must be located in the underground halls. Table 13.2 summarizes the area of the surface facilities. (**Ed:** *this is very brief!*)

Table 13.2: Asian site surface facilities

Source Area	Qty	Area (m^2)	% Area
e^- source	0	0	0.0%
e^+ source	0	0	0.0%
Damping Ring	0	0	0.0%
RTML	0	0	0.0%
Main Linac	65	22,375	24.5%
BDS	10	3,650	4.0%
IR	28	65,250	71.5%
TOTAL	103	91,275	100.0%

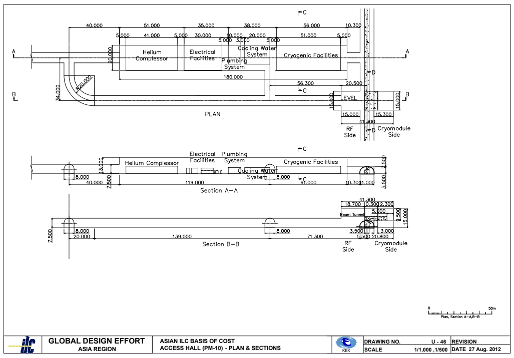


Figure 13.5: Access Hall (**Ed:** *todo: crop figure)*

13.5.3 Mechanical

The main aspects of the mechanical design are:

Table 13.3: Main linac RF heat loads.

Area System	load to LCW	load to Air	Conventional	Cryo (Water load)	Total
e^- sources	1.40	0.70	0.80	0.80	3.70
e^+ sources	5.82	0.64	1.51	0.59	8.56
DR	10.92	0.73	1.79	1.45	14.89
RTML	4.16	0.76	0.68		5.60
Main Linac	42.34	5.29	5.26	40.50	93.40
BDS	9.20	1.23	3.23	0.41	14.07
Dumps	14.00		0.05		14.05
IR	0.40	0.76	0.10	2.65	3.91
TOTALS	88.24	10.11	13.42	46.40	158.18

- The location and quantity of the main linac (ML) heat loads (Table 13.3) are based on the DKS. Cryomodules are in a 9-cryomodule string and RF is fed by klystrons and modulators installed in the service gallery. As a staged approach, initially one klystron feeds 4.5 modules located every 54 m. Later, more klystrons are added and each klystron feeds 3 modules every 36 m. Chilled water is used to cool instrument racks and the gallery air.

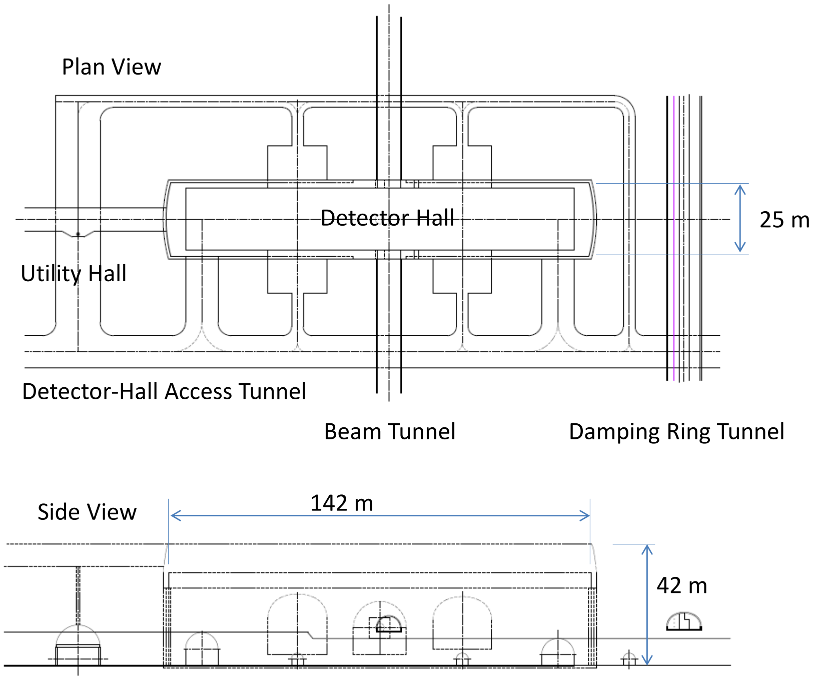


Figure 13.6: IR Hall

- The cooling-water plants are located next to the cryogenic plants in the access halls underground. Heat is transferred through the access tunnels and released to the air by cooling towers on the surface. Cryogenic warm compressors are distributed along the underground service gallery.

- 90% of the heat loads are cooled by processed water at a temperature of ~34 °C. About 10% of the heat loads such as air conditioning and racks are cooled by chilled water at ~ 9 °C. The processed water and chilled water loads treated in each access halls are summarized in Table 13.4.(**Ed:** *placeholder figure is inserted in place of the table)*

13.5.3.1 Processed water

The heat loads are distributed up to ± 2.5 km from the nearest access hall. Considering both construction costs and operational safety, the cooling-water system is

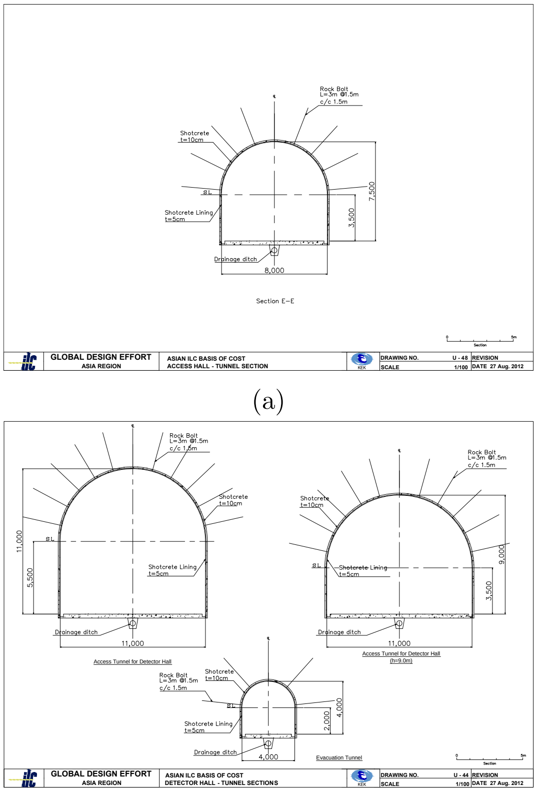
Table 13.4: Heat loads grouped by access halls.(**Ed:** *Table does not fit and needs to be rotated)*

LCW /Process Water

Shaft Number	PM-12	PM-11	PM-10	PM-9	PM-8	PM-7	PMB-0	PXA	PXB	PMC-0	PM+7	PM+8	PM+9	PM+10
ML racks-surface load														
CRYO - surface load	7.61		8.49		4.84			3.06		1.45		4.84		8.49
RTML-tunnel load	2.00				0.08							0.08		
ML (RF, raks & magnets) tunnel	7.17		9.41		4.70							4.48		9.41
DR-tunnel load							2.19			8.73				
e+ source-tunnel load					5.82									
e- source-tunnel load												1.40		
BDS-tunnel load					4.60							4.60		
Dumps-tunnel load									14.00					
IR-tunnel load								0.40						
Conventional loads	1.23		1.17		3.71		0.36	0.10	0.05	1.43		2.97		1.17
GRAND TOTAL	18.01	0.00	19.07	0.00	23.75	0.00	2.54	3.56	14.05	11.62	0.00	18.38	0.00	19.07

Chilled Water /Process Water

Shaft Number	PM-12	PM-11	PM-10	PM-9	PM-8	PM-7	PMB-0	PXA	PXB	PMC-0	PM+7	PM+8	PM+9	PM+10
ML racks-surface load														
CRYO-surface load														
RTML-tunnel load	0.36				0.02							0.02		
ML (RF, raks & magnets) tunnel	0.90		1.17		0.59							0.56		1.17
DR-tunnel load							0.15			0.58				
e+ source-tunnel load					0.64									
e- source-tunnel load												0.70		
BDS-tunnel load					0.62							0.62		
Dumps-tunnel load														
IR-tunnel load								0.76						
Conventional loads	0.00		0.00		0.00		0.00	0.00	0.00	0.00		0.00		0.00
GRAND TOTAL	1.26	0.00	1.17	0.00	1.86	0.00	0.15	0.76	0.00	0.58	0.00	1.89	0.00	1.17



(a)

(b)

Figure 13.7: Underground access tunnels.(**Ed:** *todo: crop figures*)

based on 3-loops as shown in Fig. 13.8. The first loop includes surface cooling towers, pumps, and piping underground. The second loop provides processed cooling water ± 2.5 km in both directions along the ML service gallery. The heat exchanger protects underground equipment against high water pressure from the surface. The third loop provides low conductivity water (LCW) to the local heat loads.

13.5.3.1.1 Cooling towers The cooling towers are open-water-type because of the advantages of lower construction cost, smaller footprint, and lower noise. The evaporation rate of 600 m^3/h for cooling 200 MW of heat load can be compensated with inflow water, which would otherwise need to be disposed of. A group of cooling towers with one stand-by tower is located at each access tunnel entrance, supplying

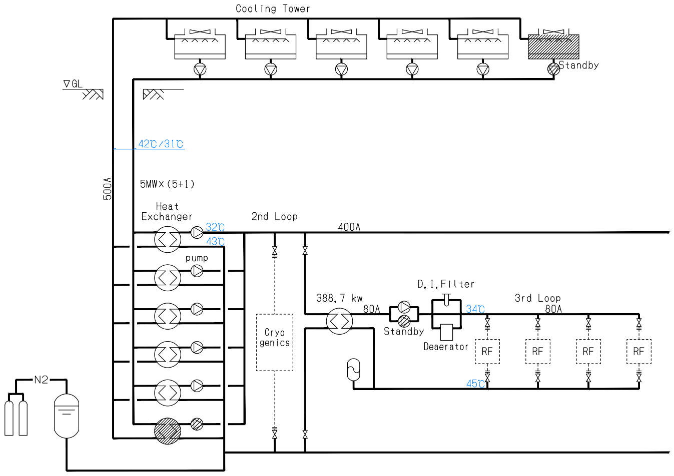


Figure 13.8: The cooling water system in AH2.**(Ed:** *todo: crop figure)*

cooling water of 31 °C from a reservoir temperature of 27 °C, and returning water of 42 °C**(Ed:** *check!)* .

13.5.3.1.2 Underground cooling-water loops The second loop temperature is 32 °C in supply and 43 °C in return water. The second loop has also a group of heat exchangers and pumps with one back-up. The third loop, which finally cools the accelerator technical equipment, needs to supply deoxygenated and demineralized water via stainless-steel pipes. It feeds four RF units using a compact cooling-water unit with heat exchanger, pump, de-aerator, and de-ionizer. The temperature is 34 °C in supply and 45 °C in return.

13.5.3.1.3 Chilled-water system The chilled-water system is similar to the cooling -water system except it includes a refrigerator (Fig. 13.9). Chilled water is produced by "Inverter-Turbo"-type refrigerators which have high efficiency and less CO_2 gas emission. The system configuration is also three-loop. The third loop covers four RF units and the water temperature is 7 °C at the supply and 18 °C in the return.

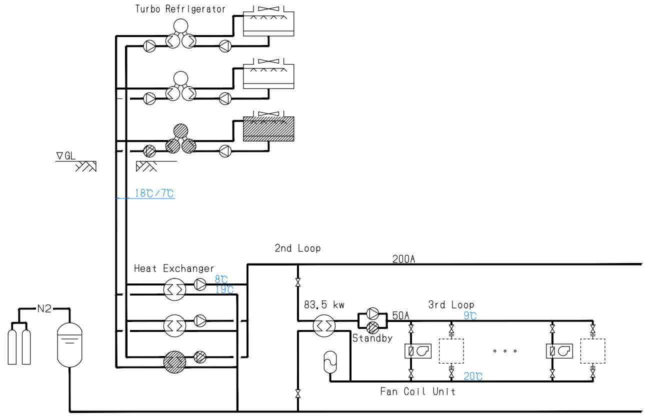


Figure 13.9: The chilled-water system (access hall 3).**(Ed:** *todo: crop figure)*

13.5.3.2 Piped utilities

Figure 13.10 shows a flow chart of the piped utilities. The municipal water system is used for potable water. It is stored in tanks both on the surface and underground. Sewage water is purified and sent to a drain sewer on the surface.

The inflow water outside the thick tunnel lining is collected in a tank at each access hall. Water leaking inside the tunnel is collected to pits located at intervals and pumped to the access hall tank. This water is monitored for activation, and if activated, stored in a holding tank. Otherwise, it is merged into the inflow water and pumped to the surface. Part of the water is sand-filtered and utilized for the cooling-tower makeup water.

13.5.3.3 Air treatment

Fresh ambient air is treated by air conditioning equipment on the surface. The air is cooled and dehumidified in the summer and heated in the winter, and supplied to the underground structures by a large-bore duct installed in the access tunnel. The air blows in the tunnel without ducts at a flow rate of $\sim 0.5\,\mathrm{m/\,s}$. The tunnel is $29\,^{\circ}\mathrm{C}$ temperature and 35% humidity. The service tunnel is cooled by fan-coil units

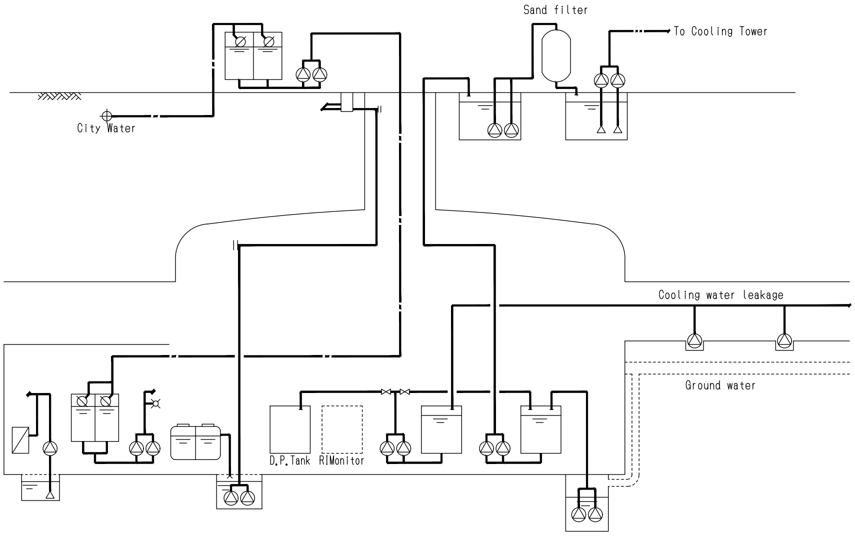


Figure 13.10: Piped utilities.

using chilled water. The air is exhausted to the surface. The atmospheric pressure is controlled by dampers in the ducts so that the pressure of the service tunnel is slightly higher than the beam tunnel. The exhaust duct is also the smoke exhaust in the case of fire. Helium leakage is vented through the small-bore survey shafts located every ∼2.5 km (Fig. 13.11).

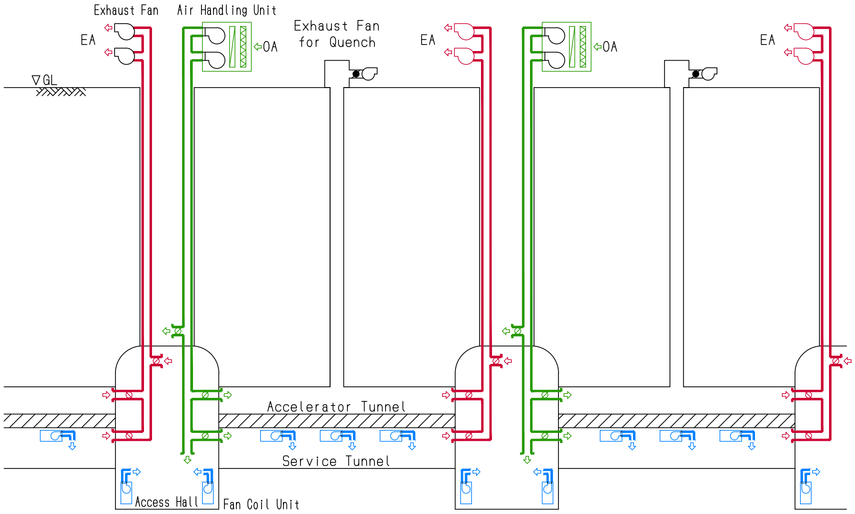


Figure 13.11: Caption **(Ed:** *missing caption)* .

13.5.4 Electrical

(**Author:** *Common descriptions for both KCS and KDS)*

RF is provided through the DKS. The power loads are given in Table 13.5. The major difference from KCS is in terms of the location and number of RF sources.

Table 13.5: Estimated nominal power loads (MW) at 500 GeV center-of-mass operation.

Area System	RF Power	Racks	NC magnets	Cryo	Conventional		Total
					Normal	Emerg	
e^- sources	1.28	0.09	0.73	0.80	1.02	0.16	4.08
e^+ sources	1.39	0.09	4.94	0.59	2.19	0.35	9.55
DR	8.67		2.97	1.45	1.84	0.14	15.07
RTML	4.76	0.32	1.26		0.12	0.14	6.60
Main Linac	52.11	4.48	0.91	40.50	8.02	5.12	111.15
BDS			10.43	0.41	0.24	0.28	11.36
Dumps					1.00		1.00
IR			1.16	2.65	0.09	0.17	4.07
TOTALS	68.21	4.98	22.40	46.40	14.52	6.36	162.88

13.5.4.1 Electrical power distribution

The electric power is distributed in three stages:

- The site electric power is stepped down from local-district high-voltage (150-500 kV) to 66 kV in the main substation and distributed to 6 access hall and the IR hall substations.
- The 66 kV electricity is further stepped down to 6.6 kV at eachsubstation and distributed inside the areas.
- The electric loads such as RF modulators and cryogenic warm compressors are powered directly at 6.6 kV and other local loads are fed at lower voltages stepped down in local substations distributed along the accelerator.

13.5.4.2 Main substation and 66 kV power distribution

A primary voltage of 275 kV was assumed for the site. The single-line diagram of the main substation is shown in Fig. 13.12. The primary line configuration is a two-way system including a stand-by line. The power capacity is designed to be 300 MW and space is reserved for an additional 200 MW for the future 1-TeV upgrade.

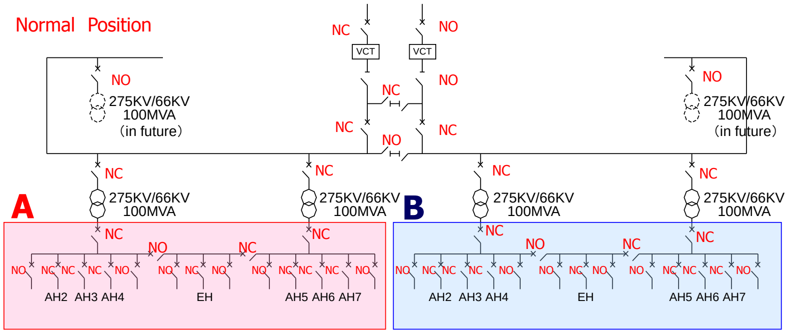


Figure 13.12: Single-line diagram for the main substation.**(Ed:** *todo: crop figure)*

The main transformers have an n+1 redundancy scheme and use four banks of 100 MW transformers. The switching gears are gas insulation type. They are located in an outside yard of area ~4000 m^2. The secondary voltage is 66-kV and the power is distributed through the BDS and ML service galleries access halls with two pairs of three-phase cables.

13.5.4.3 Access hall substations

The power distribution from the main substation to the underground access halls is summarized in Table 13.6.**(Ed:** *placeholder figure is inserted in place of the table)* Because the power range is between 28 MW and 44 MW, there are two 30 MVA 66 kV/6.6 kV transformers at each substation, allowing more than a half of the operational power to be maintained in case of a transformer fault. There is one spare transformer at the main substation, with capacitors to improve power efficiency. The single-line diagram and the equipment layout in the hall are shown in Fig. 13.13.

Table 13.6: Power distribution to underground halls.

Shaft Number	PM-12	PM-10	PM-8	PMB-0	PXA	PXB	PMC-0	PM+8	PM+10	PM+12	Total
Surface technical loads	7.61	8.49	4.84	0.00	3.06	0.00	1.45	4.84	8.49	7.61	46.40
ML (RF & racks)											0.00
Cryo	7.61	8.49	4.84		3.06		1.45	4.84	8.49	7.61	46.40
Tunnel technical loads	12.78	12.78	12.93	2.33	1.16	10.43	9.31	8.31	12.78	12.78	95.59
RTML	3.04		0.13					0.13		3.04	6.33
ML (RF, racks, NC magnets)	9.74	12.78	6.39					6.09	12.78	9.74	57.51
DR				2.33			9.31				11.64
e+ source			6.42								6.42
e- source								2.10			2.10
BDS						10.43					10.43
Dumps											0.00
IR					1.16						1.16
Conventional loads	2.35	2.92	4.00	0.60	1.26	0.52	1.43	2.57	2.92	2.35	20.92
Normal power	1.41	1.78	3.08	0.52	1.09	0.24	1.36	1.87	1.78	1.41	14.55
Emergency power	0.93	1.14	0.92	0.08	0.17	0.28	0.07	0.70	1.14	0.93	6.37
TOTAL	22.74	24.19	21.77	2.93	5.48	10.95	12.19	15.72	24.19	22.74	162.9
66 kV / 6.6 kV transformer	30 MVA	30 MVA	30 MVA	30 MW, 30 MW (30 MW)				30 MVA	30 MVA	30 MVA	

13.5.4.4 Local substations

The local distribution board diagram is shown in Fig. 13.14. There are 6.6 kV boards for modulators every four RF units and cryogenic compressors in the access halls. The local substations step down 6.6 kV to lower voltages every four RF units.

13.5.4.5 Emergency electrical power

13.5.4.5.1 Emergency generator There are emergency generators at each of seven 66-kV substations. The emergency power generators are adequate for fire-fighting and to maintain minimal functioning of the building and the compressor for He gas storage during an electricity outage. Each of seven diesel-engine generators installed at the surface yards supplies the underground 66-kV substation with ~1 MVA power.

13.5.4.5.2 DC power supply DC power supplies are used for the substation control system and emergency lights. They are installed in seven AHs and the DH. Chargeable batteries are used for tunnel emergency lights, evacuation lights, and local substations. The equipment is a cubicle system and MSE Batteries are used.

13.5.4.5.3 Uninterruptible power system (UPS) For monitoring the service equipment status, UPSs are installed in each control room beside the substations.

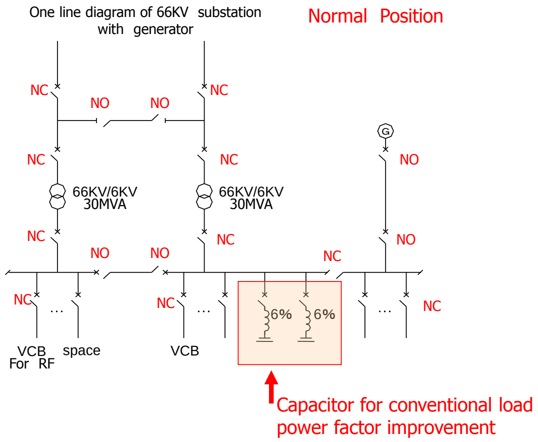


Figure 13.13: Access hall substation single-line diagram and the equipment layout.

Technical equipment includes its own UPS where necessary.

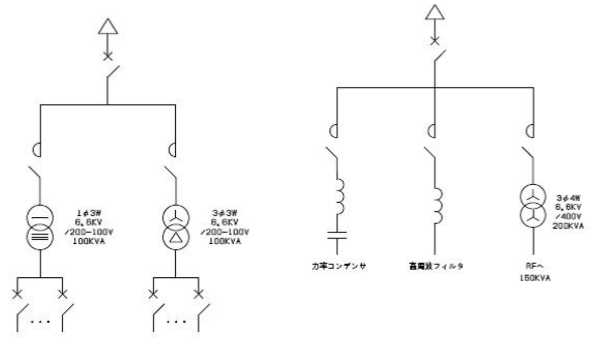
13.5.5 Life safety and egress

13.5.5.1 Fire safety

There are no existing laws and design guidelines in Japan which specify safety and disaster prevention measures for deep underground tunnels. A special committee established by the Japan Society of Civil Engineers is currently reviewing the basic policy proposal on the disaster prevention design for the ILC underground facilities. The following shows the present safety measures planned based on a conventional accelerator tunnel. Of primary importance in an underground tunnel is safe refuge when a fire breaks out. However, the distance to the surface via an access hall can be as long as 5-6 km and a redundant evacuation route is critical. This is provided by the access passage located every 500 m which connects the two galleries so the other gallery can provide an escape route for evacuation.

Evacuation from the tunnel to the surface is via the access hall and the access tunnel every 5 km. Even with rapid egress, it can take up to 1 hour to reach the surface. If a fire is detected, the partition door and damper for the access passage will close automatically, and will prevent smoke reaching the escape route.

Each of the two galleries is separately ventilated from the access halls. There is no separate emergency smoke control system. The main ventilation system switches to a smoke-exhaust function automatically in case of a fire.



(a) (b)

Figure 13.14: The local distribution panels.(**Ed:** *figure quality poor)*

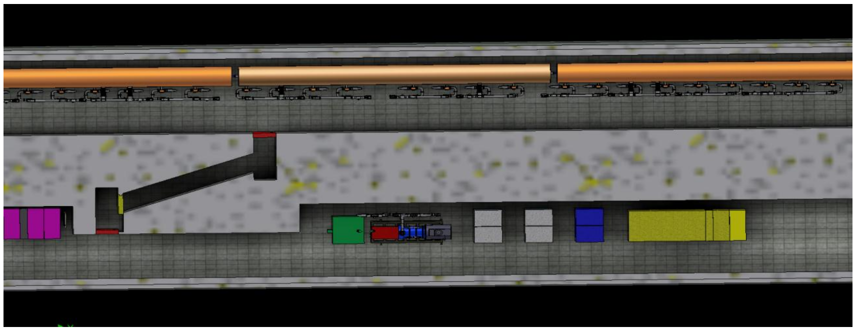


Figure 13.15: Missing caption(**Ed:** *Missing caption)* (**Ed:** *figure quality poor)*

There is no installed fire-extinguishing sprinkler system to avoid possible water damage to the accelerator machine and experimental equipment. The ML tunnel is equipped with the following standard emergency equipment.

- Smoke detector and fire detector
- Fire alarm system
- Emergency lighting system
- Emergency illuminated exit signs
- Emergency exit guide lights
- Fire extinguishers

13.5.5.2 Safety for Helium

Since there is a large quantity of liquid helium in the tunnel, oxygen deficiency monitoring is required throughout the beam tunnel. When the oxygen concentration drops below an acceptable level, emergency measures are taken and an alarm sounds. The main ventilation system switches to emergency-mode and the helium gas from the upper part of the tunnel is discharged outside by exhaust shafts in the access tunnels.

13.6 European region (Flat topography)

13.6.1 Siting studies

Two European sites were considered: the Geneva region (deep site study), along the French-Swiss border and the Dubna region (shallow site study) in Russia.

The European CFS design is based on the KCS RF concept developed by the Americas Region. This system assumes that as much as possible of the technical equipment is housed on the surface in order to minimise the underground enclosure volumes.

13.6.1.1 Geneva region (deep site)

13.6.1.1.1 Location The location for the European design of the ILC is set in the North Western part of the Geneva region, near the existing CERN laboratory. Figure 13.16 shows the potential siting for the nearly 31 km long tunnel. Since no real discussions with local authorities have taken place, this position is only indicative. The interaction region (IR), is fully located within existing CERN land at the Prevessin Campus. The new underground structures will mostly be constructed at a depth of 100-150 m in stable Molasse rocks in an area with moderate seismic activity.

All necessary infrastructure to accommodate the ILC project is available in the Geneva area. This includes the possibility of accommodating specialists for the accelerator construction period, storage and assembly of equipment, and the provision of project-production support during manufacturing of the special-purpose equipment. Excellent transport and communication networks already exist.

The governments of France and Switzerland have long standing agreements concerning the support of particle accelerators in the Geneva region, which make it very likely that the land could be made available free of charge, as it was for previous CERN projects.

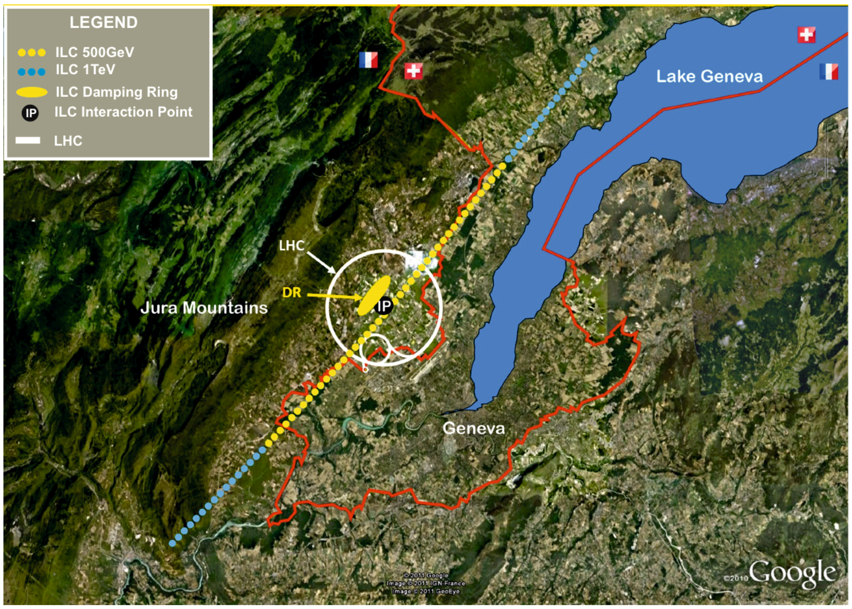


Figure 13.16: Map showing the potential location for ILC

13.6.1.1.2 Land Features The proposed location for the accelerator is situated within the Swiss midlands embedded between the high mountain chains of the Alps and the lower mountain chain of the Jura. CERN is situated at the foot of the Jura mountain chain in a plain slightly inclined towards Lake Geneva. The absolute altitude of the surface ranges from 430 m to 500 m with respect to sea level.

13.6.1.1.3 Climate The climate of the Geneva region is temperate, with mild winters and warm summers. Westerly winds predominate, transporting moist maritime air to the area. The mean annual air temperature is 9.6 °C, with a maximum temperature of 25.7 °C in July and a minimum temperature of −1.9 °C in January. The mean annual relative humidity is 75%. Precipitation is well-distributed throughout the year, with a mean annual precipitation of 954 mm. An average of 42.5 cm of snow falls in the period November to March.

13.6.1.1.4 Geology Most of the proposed path of the ILC is situated in the Geneva Basin, a sub-basin of the large North Alpine Foreland (or Molasse) Basin. Characterized as stable and impermeable, the Molasse rock is considered to be very suitable for underground constructions. A simplified geological profile of the region is shown in Fig. 13.17.

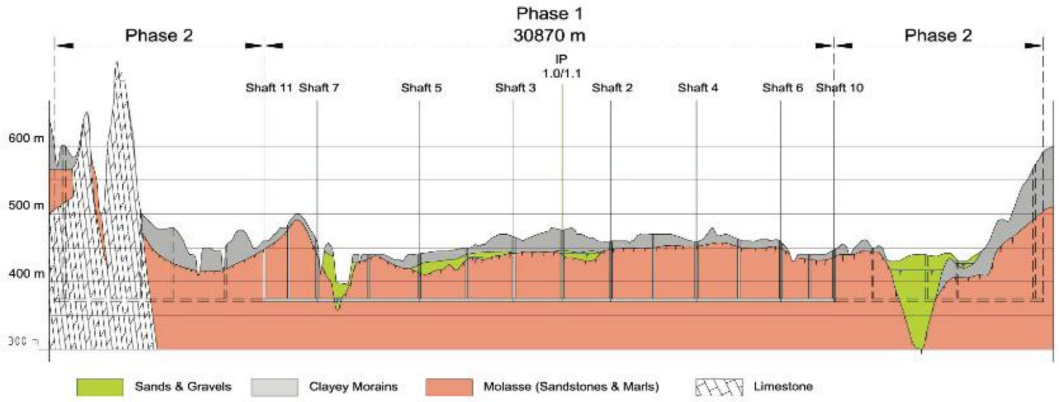


Figure 13.17: Simplified geological profile. ILC is mostly housed in the Molasse Rock.

13.6.1.1.5 Power Availability (Ed: *Empty section*)

13.6.1.1.6 Construction Methods For the upper parts of the shafts, located in dry moraines up to 50 m depth, traditional excavation means are foreseen. Where water bearing units are expected to be encountered, e.g., “Gland” valley, the ground freezing technique will be used to allow safe excavation of the shafts under dry conditions. This technique involves freezing the ground with a primary cooling circuit using ammonia and a secondary circuit using brine at $-23\,^{\circ}\mathrm{C}$, circulating in vertical tubes in pre-drilled holes at 1.5 m intervals. Besides creating dry conditions, the frozen ground acts as a retaining wall.

When the underlying rock (sandstone) is reached the shafts and caverns will be excavated using rock breakers and road headers. A temporary lining will be set in place using rock bolts, mesh and shotcrete, after which the walls and vaults will be sealed with waterproof membranes and covered with cast in-situ reinforced concrete.

The machine tunnel extending from the IR for the BDS & Sources, requires underground encloses with diameters varying from 5.2 m, 6.0 m, 8.0 m up to 12.0 m. For the Molasse rock, it is estimated that it is cheaper to excavate these tunnels using a TBM with 8.0 m diameter for the entire length of the BDS tunnels, with some local cavern enlargements using Roadheaders in a second phase.

13.6.1.2 Dubna Region (shallow site)

13.6.1.2.1 Location The Dubna area is a potential shallow tunnel site for the ILC. The Joint Institute for Nuclear Research (JINR) has essential benefits and privileges as an International Intergovernmental Organization and has a unique experience in organizing and successfully realizing large-scale research projects based on a wide international cooperation of scientific centers and industrial enterprises. Figure 13.18 shows the potential siting for the 31 km long tunnel.

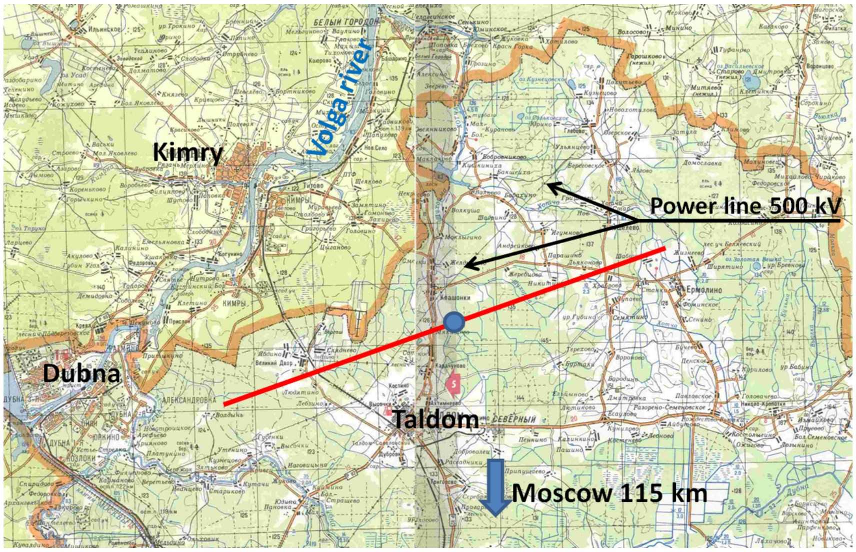


Figure 13.18: The proposed path of the accelerator construction (indicated as a red line) in the Dubna region

Due to the special economic zone, established in Dubna in December 2005, preferential terms for the development and manufacturing of high technology products are provided. Furthermore, the prevalent legal conditions in the Dubna region provide the opportunity for ILC to acquire land free of charge, as has been the case for JINR, with the agreement between JINR and the RF government.

13.6.1.2.2 Land features The main feature of the proposed location is a flat topography, with an absolute altitude ranging between 125 m to 135 m with respect to sea level. The relief increases away from the site as the plain changes into smoothly sloping separate hills. The area is often swampy, with waterlogging conditions. The Dubna river floods have a profound influence on this process. During floods the groundwater level increases up to 0.6 m-0.9 m, and a high percentage of the area often becomes flooded. The proposed territory is sparsely populated and practically free of industrial structures. The region around the accelerator path is mainly covered with forests containing small inclusions of agricultural lands. The path of the accelerator traverses two small settlements and a railway with light traffic between the towns Taldom and Kimry. The construction of the ILC will not affect national parks or religious and historical monuments. Developed infrastructure and communication systems are in place.

13.6.1.2.3 Climate The region is characterized by a moderate continental climate with long and relatively cool winters and warm summers. The average annual air temperature in the region is +3.10 °C, with the absolute maximum air temperature of +36.0 °C and an absolute minimum temperature of -43.0 °C. The average maximum air temperature of the hottest and coldest months is +22.70 °C, and -19.0 °C respectively. The average monthly relative air humidity in the region during the coldest and the hottest month in the year is 84% and 57%. The annual rainfall is 630 mm, of which 447 mm precipitates during the warm period (April-October) and 183 mm during the cold period (November-March). Snow covers the region on average from November 26 onwards with an average snow depth of 30-40 cm in open places during the winter period.

13.6.1.2.4 Geology The proposed alignment of the ILC is situated within the Russian Plate, which is a part of the ancient East-European platform. The area is located in the southern part of a very gently sloping saucer-shaped structure, called the Moscovian syncline. The top layer consists of alluvial deposits, i.e., fine water-saturated sands with a varying thickness of 1 m to 5 m. These deposits cover the underlying semisolid drift clays, called moraines, of the Moscovian glaciation, which contains inclusions of detritus and igneous rocks. The thickness of the moraine deposits is between 30 m and 40 m. The moraines cover the fluvio-glacial saturated sands and loams of the Dnieper glaciation. Jurassic clays and carboniferous limestones are located at a depth of 50 m–60 m. The region is located in a low seismic activity.

As the ILC is proposed to be placed in the moraines, at the depth of 20 m, an impermeable soil layer should be present under the tunnel to prevent water inflow from underlying water bearing units (see Fig. 13.19).

Overall, the results of the obtained data show that the geological, hydrological and geotechnical conditions are favorable for placing the linear collider in the Dubna region.

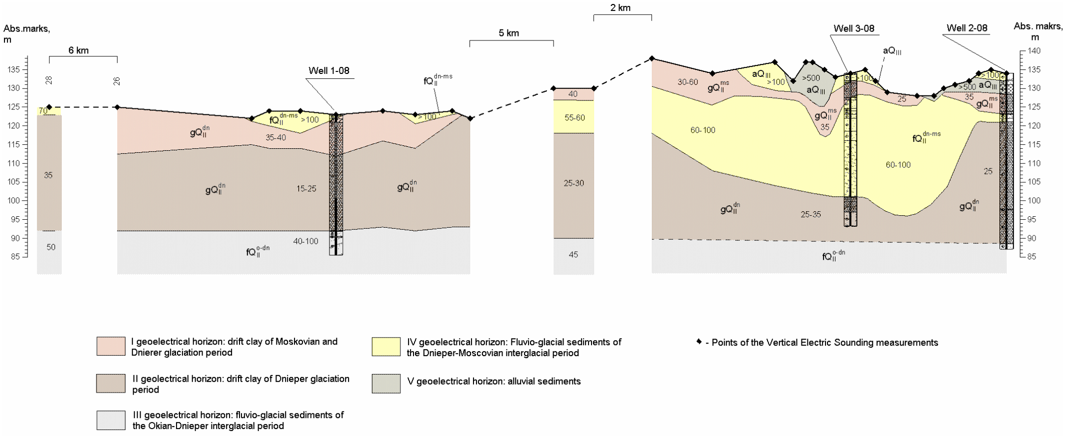


Figure 13.19: A geology study near Dubna

13.6.1.2.5 Power availability The northern part of the Moscow region, as well as the neighboring regions, has a developed electrical energy generation, transmission and distribution network through the first-rate generating stations: the Konakovo EPS (electric power station) and the Udomlia APP (atomic power plant). Two trunk transmission lines with the voltage of 220 kV and 500 kV pass through the Dubna territory. The proposed path of the ILC is deliberately placed along these power lines at some distance.

13.6.1.2.6 Construction methods A one-tunnel solution for the accelerator structure and conventional facilities is possible for the Dubna site. The primary tunnel housing the accelerator will be located at a depth of $\sim$20 m, ensuring the presence of an impermeable stratum above and below the tunnel as to prevent the breakthrough of groundwater. A communication tunnel will be placed directly above the underground accelerator tunnel near the ground surface at the depth of 3 m-4 m. This tunnel is necessary for power supplies, RF power sources, data storage devices, electronic and control systems, etc. Near sub-surface buildings would be constructed by an open pit method and the tunnel might best be constructed by a boring machine. However, ‘cut&cover’ construction techniques are possible over nearly the whole length.

13.6.2 Civil construction

The European design for the ILC machine is developed to fit the local geological and environmental constraints of the Geneva area. A key focus of the design phase has been to create a cost-efficient technical design, giving special attention to Conventional Facilities and Siting (CFS) studies to minimize the infrastructure costs, such as civil engineering, which are the main cost-drivers of the project.

This section describes the technical designs for the civil engineering for the 500 GeV machine scenario. The studies are performed by a collaboration of ILC specialists and external consultants[1].

13.6.2.1 Overall site layout

Figure 13.20 shows a schematic layout of the civil engineering complex. The key characteristics of the ILC baseline layout are:

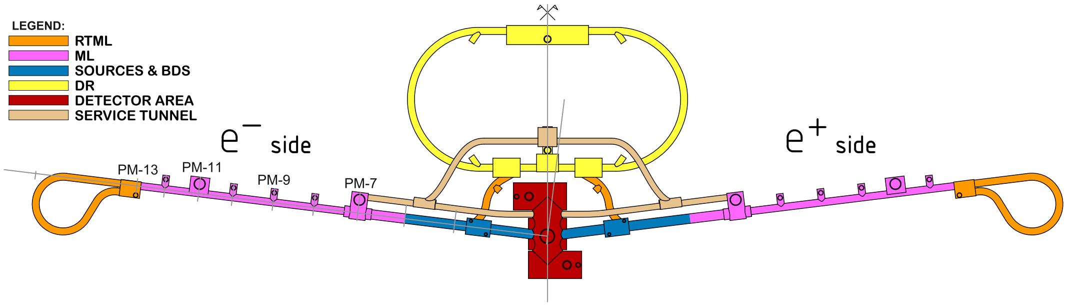


Figure 13.20: Schematic layout of the civil engineering complex

- Tunnel footprint of approximately 31 km, positioned at 100-150 m depth
- Tunnel is horizontal and not laser straight as CLIC
- Interaction Region (IR) and Injection complex fully located on the Prevessin Campus,
- ML is housed within a single tunnel with an internal diameter of 5.2 m
- Two turn-around tunnels connected to the ML with a bending radius of 30 m in the horizontal plane

---

[1] *Amberg engineering AG*, contact person Mr. J. Brasser, *ARUP*, contact person Mr. M. Sykes, *Gadz Geotechnique Appliquee Deriaz SA*, contact person Mr. J-F. Hotellier

- Two independent caverns for detector assembly & maintenance linked with a common ‘passageway’ through a transfer tunnel.
- Shafts and surface installations approximately every 2 km

13.6.2.2 ML tunnel

The ML is housed in a single tunnel with an internal diameter of 5.2 m and an extra 10 cm margin to allow for construction tolerances. In the tunnel the largest area (2780 m length) is reserved for the machine components, including the cryomodules, while still allowing space (2420 m length) for transportation and a safety passage. Furthermore, 34 alcoves are located in the tunnel. Figure 13.21 shows a typical cross section of the ML tunnel. The diameter is optimized through 3D modeling to understand the underground volume required for housing the ILC machine and its services. The diameter is within the common range of TBMs used for metro transportation tunnels. Therefore machinery and spare parts are easily found on the market.

A service tunnel, linking the ML with the IR hall and the Damping Ring is foreseen. The ML is furthermore connected at both ends to 8 m diameter RTML turn-around tunnels, with an average bending radius of 30 m in the horizontal plane. Two additional RTML tunnels are planned for the Central Injector Region, connecting the Drive Ring and the sources.

A driving factor of the tunnel size is the ventilation concept. Mainly for safety reasons, a transversal ventilation concept is adopted. This differs from the LHC, which has a longitudinal ventilation scheme. Cryo-modules are attached directly on the tunnel floor, which is compatible with the transversal ventilation concept, minimizes ground movement and allows for easy intervention access.

13.6.2.3 Central injection region

The central injection complex is fully housed at CERN on the Prevessin Campus. It consists of Damping Rings, polarized electron and positron sources and the electron and positron 5 GeV SCRF injector linacs. Figure 13.22 shows a model of the Central Injection Region.

The Damping Ring complex is an approximately 3 km long quasi-circular tunnel with an internal diameter of 6 m and containing 4 alcoves. Two 9 m-diameter shaft are foreseen, one in the middle of each long straight sections of the complex. The tunnel houses both the electron and positron damping rings. It is connected to the main LINAC through two 250 m long Ring to Main LINAC (RTML) tunnels, the

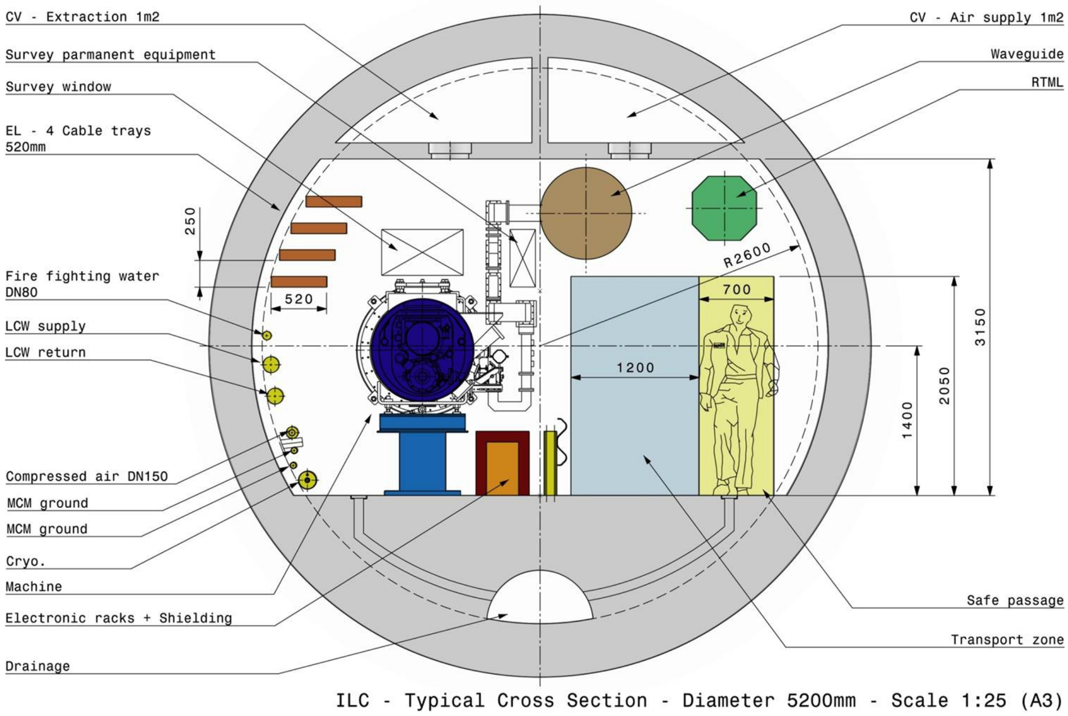


Figure 13.21: Typical tunnel cross section.

ELTR and PLTR transfer tunnels, with an internal diameter of 6 m. The electron and positron injector linacs are located in tunnels of 8 m internal diameter. The sources are housed in 7 m diameter tunnels connected at their ends to the main LINAC. A 4.5 m-diameter service tunnel passes over the Damping Ring and connects the Ring to the Detector Area and Main accelerator.

13.6.2.4 IR and BDS

The experimental area and BDS facilities are situated in the middle of the complex (see Fig. 13.23). The interaction region (IR) houses the two detectors in two caverns that are separated by a transfer cavern. The two 60 m diameter experimental areas contain an 8 m diameter shaft. Both detector caverns are connected to a sub-cavern, with a 6 m diameter shaft. Escape tunnels connect each of the detector caverns with a safety shelter located in the other detector cavern.

(**Ed:** *Don't we need an IR hall layout also?)*

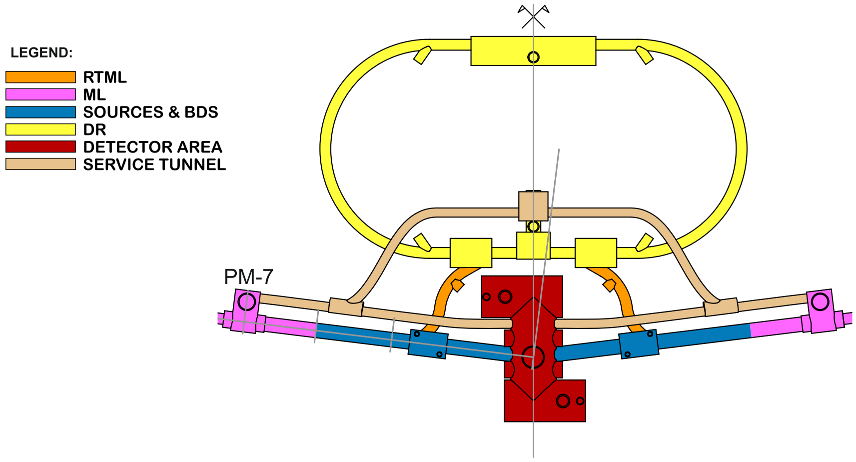


Figure 13.22: Model of the Central Injection Region.

A survey gallery allows the alignment of magnets located in the beam tunnels on both sides of the IR. Before being lowered to the ground, the detectors will be assembled and tested in a Surface building. An 18 m-diameter shaft connects this surface building to the Transfer Cavern which in turn connects the two Detector Caverns. Travelling cranes will have to be installed to allow the assembly and servicing of the detectors. The surface building is equipped with a temporary 2000 t gantry crane and the transfer cavern is equipped with a 20 t crane.

The designed detector platform allows the sliding of a detector in beam position through a push and pull system. With the help of the UK based consultancy firm, ARUP, the deflection of the invert slab is assessed to be 0.8 mm at the critical region of the moving slab supports. This value is thought to be tolerable for this pre-phase study. More information is available in the MDI chapter.(**Ed:** *put the slab details in MDI)* Additionally, ARUP studied the geotechnical and structural behavior of the ground-detector complex interface, using existing local geological data and known geotechnical rock characteristics available at CERN. A 3D model has been developed to understand the stress conditions of the underground cavern complex at the IR. The analysis identified the in-situ stress development across the IR and has shown that the current orientation of the cavern alignment is preferred.

The BDS handles the incoming and outgoing beams in and out of the IR. It houses several beam dump caverns (e^- and e^+ tune-up dump, e^- and e^+ fast abort dump, photon dump), positron capture chicanes, target bypass 'dog-leg' areas, undulator areas and service caverns for equipment storage. The beam dump facilities are

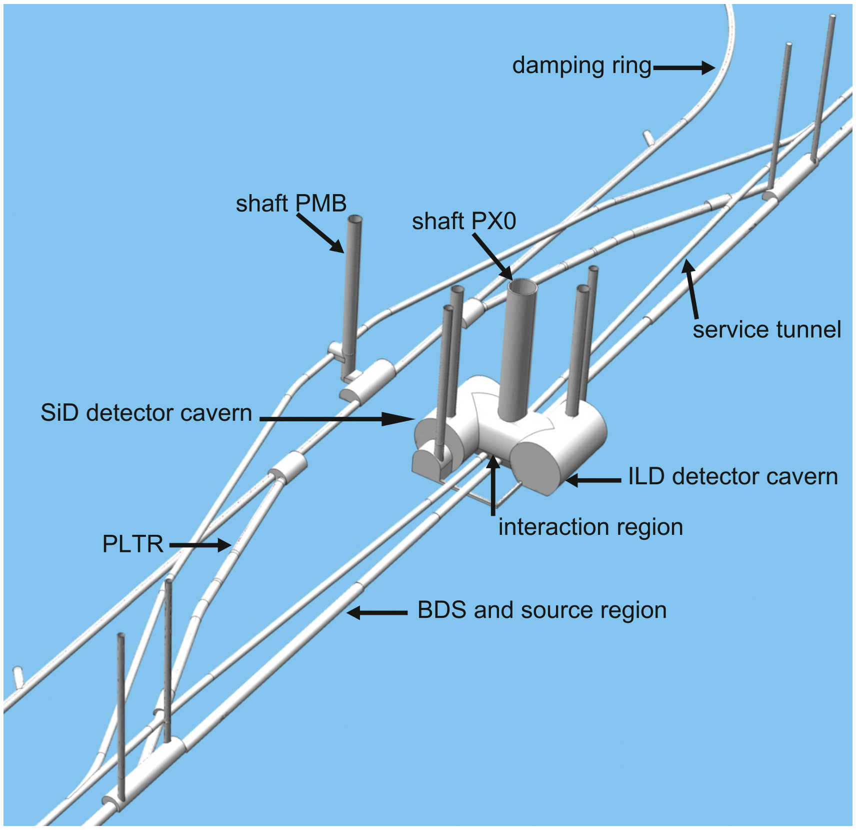


Figure 13.23: Model of the Central Injection Region.

located at both sides of the IR in caverns accommodation high water pressure water dump tanks. Figure 13.24 shows the e^- tune-up dump area, including the location of the water tank.

13.6.2.5 Surface facilities

Surface buildings are foreseen approximately every 2 km along the ILC surface alignment in a rural environment with easy access for large vehicles. This includes surface equipment buildings, together with cooling towers and pump stations, cryo buildings, shaft head buildings, storage areas, and assembly areas. As local workshops and technical offices are already in place at CERN, these are not considered.

A large part of the buildings are expected to be located at the Prevessin Campus,

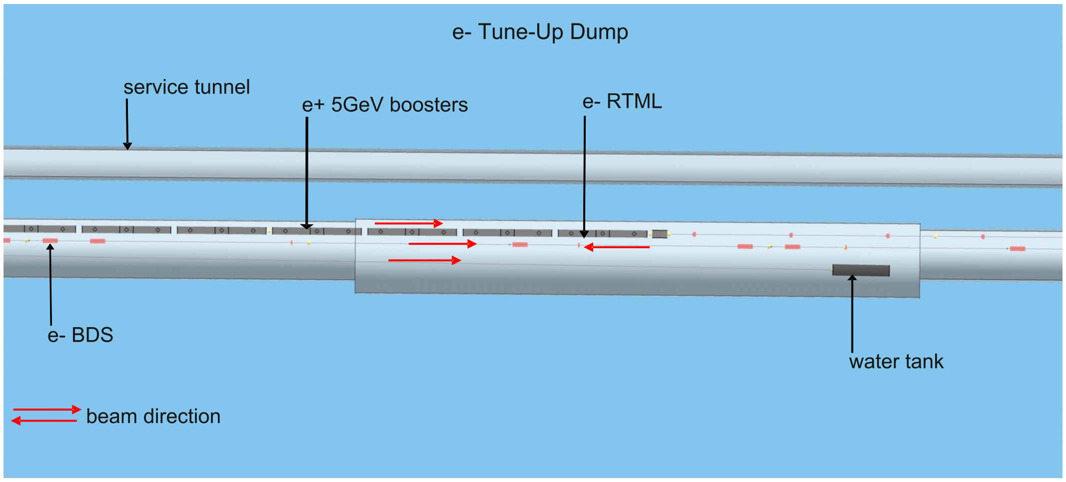


Figure 13.24: Model of the e^- Tune-Up Dump region.

near the IR. Roughly every 4km stations with klystron clusters and cryo-plants have to be located on the surface. Klystron clusters without cryo-plants are located approximately every 2 km. Hybrid installations are foreseen at the outer end of the tunnels, where a single klystron cluster powers the first 1.25 km of the ML ([**?**]**(Ed:** *add citation in bib)*).

13.6.3 Mechanical

The European mechanical design is based on the America's Klystron Cluster HVAC design. However, a major main difference between the two concepts lies in the ventilation systems, which for Europe consists of an overhead ventilation scheme in the main tunnel. This scheme has been adopted for the CLIC facility, mainly due to fire safety constraints, and its design is readily applicable for the ILC accelerator complex. For more information on the mechanical design, see Section 13.7.3 and **??**.

13.6.4 Electrical

Unlike the RDR, where CERN conducted detailed electrical design studies, the basis now is the America's design. For more details, see Section 13.7.4.

13.6.5 Life safety and egress

13.6.5.1 Introduction

The goal of fire safety is to protect occupants, rescuers, facility and external population and environment, as well as to ensure the continuity of mission. This goal is extended to the whole ILC facility, including its underground premises and surface buildings. In the following sections a summary of legal constrains, fire safety strategies and measures are described. A detailed life safety study has been conducted for CLIC. From a fire safety point of view, the ILC single tunnel complex is comparable with CLIC. Therefore the CLIC life safety and egress study can be applied to the ILC facility. More detailed information can be found in **??**.

13.6.5.2 Fire Risk Assessments and scenarios

Detailed Fire Risk Assessments and scenarios will have to be made for every specific area i.e., tunnels, experiment caverns, alcoves for equipment, linking galleries, once more information is available on the layouts and the way in which they are interconnected through ventilation systems.

Before construction, approvals will have to be acquired from the Authorities Having Jurisdiction (AHJ). The AHJ will typically apply existing legislation for well-defined cases (e.g., surface buildings) and request the ILC design group to elaborate fire risk analyses for the more complex premises, such as the underground accelerator complex. As this process has become more focussed on fire scenario predictive calculation methods, it is expected this will also be the case in the near future. The AHJ will assess these analyses and has the right to add constraints and ask for design modifications to enhance fire safety.

13.6.5.3 Fire Prevention strategy

Several fire prevention strategies exist. The more efficient strategy is that of enforcing a set of multi-level “safety barriers” with a bottom-up structure to trap most of the fire events at stages with no or few consequences. In this way the probability and impact of fire events with large consequences are considerably limited. Fire prevention measures at every possible level of functional design need to be implemented to ensure that large adverse events are only possible in the very unlikely event of many barriers failure.

13.6.5.4 Fire Safety Measures

Fire safety measures encompass measures to limit the probability of fire onset, to allow early detection and intervention, to evacuate safely people in underground structures, to limit the propagation of fire and smoke and to allow firefighting and rescue.

Accelerator tunnels, in certain respects similar to road and railroad tunnels, require more detailed analysis and a solid fire safety concept, especially regarding the evacuation of people. Even when all possible mitigation factors are considered, the distance between evacuation passages is fixed between 200 m and 600 m, with a reported 500 m in the EU-directive 2004/54. To attain this goal the tunnel can be split into compartments with solid doors and fire walls, paralleling the gallery with internal longitudinal passages. An example of such a firewall is shown in Fig. 13.25.

Figure 13.25: Conceptual representation of a firewall transversal to the tunnel orientation

The action of splitting the facility into compartment needs to be accompanied by a coherent design of the ventilation and smoke handling systems. The ventilation system in the tunnel should be capable of creating a lower pressure in the compartment affected by the fire and an over pressure in the areas at the sides, as shown in Fig. 13.26. The smoke handling system should withstand the thermal impact of fire and ensure the continuity of its functioning to prevent smoke propagation from one compartment to another.

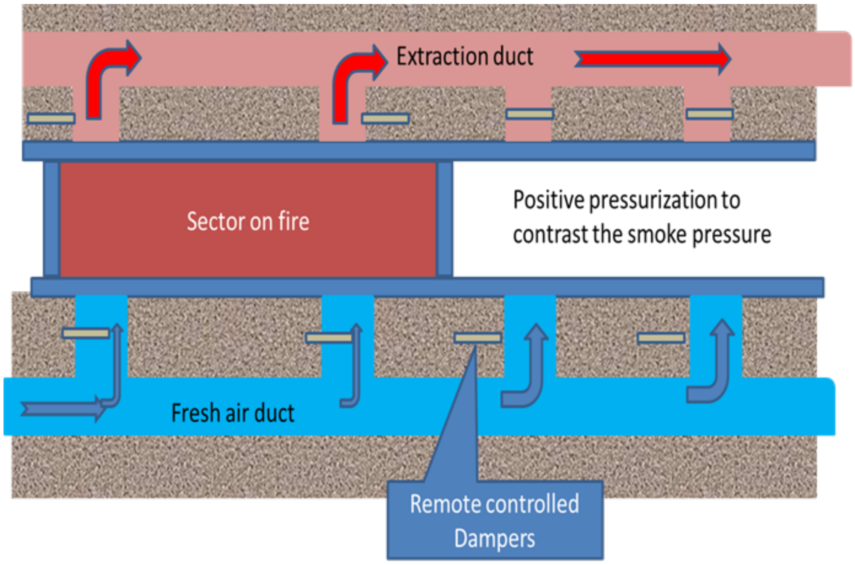


Figure 13.26: Schematic representation of the pressurization of a sector adjacent to the sector on fire

All fire safety measures need to be incorporated in the design of the facilities and equipment. As the design of the ILC complex progresses modifications to the measures my need to be required. Because the design is multi-disciplinary, involving many different groups at CERN, these groups need to be involved to ensure the integration of the measures in the design.

13.7 Americas region (Flat topography)

13.7.1 Siting studies

13.7.1.1 Location

The Americas sample site is in Northern Illinois, with a north-south orientation roughly centered on the Fermilab site. The central campus and IR are located on the Fermilab site. While the routing requires the tunnel to pass below residential areas, the shafts can be located in non-residential areas. The Fermilab site is located approximately thirty-five miles west of downtown Chicago. The surrounding area has a medium population density supported by robust utilities and transportation infrastructure.

13.7.1.2 Land Features

The existing surface of northern Illinois is primarily flat, with surface elevations ranging from 200 meters to 275 meters above sea level. Much of the eastern half of northern Illinois is developed with many commercial, residential and industrial complexes. The 2751 hectare (6800-acre) Fermilab site is also relatively flat with less than 15 meters of fall from northwest to southeast.

13.7.1.3 Climate

The climate is typical of the Midwestern United States which has four distinct seasons. In summer, temperatures ordinarily reach anywhere between 26°C to 33°C and humidity is moderate. Yearly precipitation averages 920 mm. Winter temperature averages -2°C during the daytime, and -10°C at night. Temperatures can be expected to drop below -18°C on 15 days throughout the winter season.

13.7.1.4 Geology

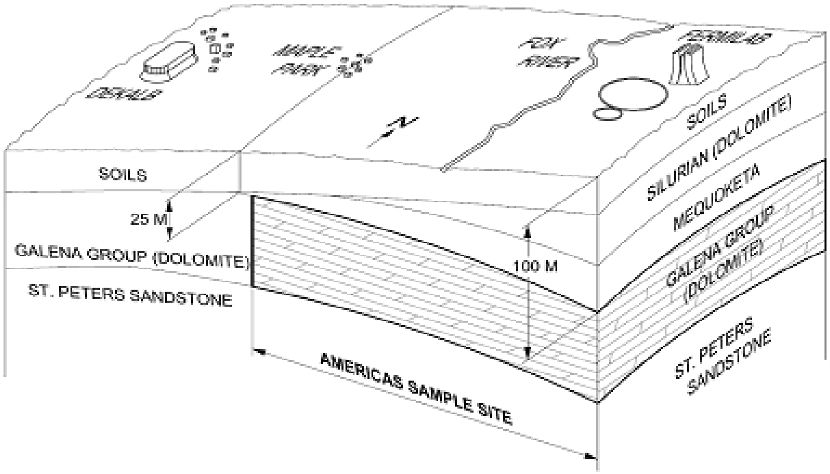


Figure 13.27: Geology of the Americas Sample Site.

The tunnels are located in a dry, uniform and massive dolomitic limestone deposit (Fig. 13.27). An overlying layer of shale provides a hydrogeologic barrier between upper aquifers and the dolomite. These geologic conditions should provide a relatively dry tunnel, both during construction and during operations, but it is expected that some grouting will be required. Geologic information has been obtained from previous underground construction at Fermilab and in northeastern Illinois, and not from ILC specific investigations.

13.7.1.5 Power Distribution System

There is approximately 35,000 MW of electric power available in the Northern Illinois area. The power is generated by fossil fuel, hydroelectric, wind and nuclear power generating systems.

13.7.1.6 Construction Methods

The tunnels are excavated with a tunnel boring machine (TBM) and lined with a cast concrete invert. Widened portions and caverns are excavated using drill and blast. Temporary supports are required for the largest spans, permanent support is provided by rock bolts. Shaft overburden is excavated using standard earth excavators and muck boxes, supported by ring beams and timber lagging, keyed into the underlying rock. Excavation through the limestone and shale to the final depth uses conventional drill and blast methods. Support is provided by resin encapsulated rockbolts and the shaft is reinforced and concrete lined.

13.7.2 Civil construction

13.7.2.1 Underground enclosures

(**Ed:** *site layout diagram needed)*

(**Ed:** *I believe the whole next section belongs in an introduction and not here, including the table)*

13.7.2.1.1 Tunnels There are a total of ∼44 km of tunnels as listed in Table 13.7.

The cryomodule waveguides are located on the aisle side of the cryomodule and are fed from circular over-moded waveguide on the tunnel ceiling. The circular over-moded waveguide comes from the Klystron Service Building located at each of the

Table 13.7: Tunnel Length and Volume by Area System

Source area	Leng. Qty (m)	Vol. Qty (m^3)	% Length	% Volume
e^- source (beam)	1,638	32,170	3.7%	3.5%
e^- source (service)	1,367	21,740	3.1%	2.4%
e^+ source (beam)	2,536	49,789	5.8%	5.5%
e^+ source (service)	1,984	31,551	4.5%	3.5%
Damping Ring	3,259	77,420	7.4%	8.5%
RTML (beam)	2,945	58,330	6.7%	6.4%
RTML (service)	2,105	33,482	4.8%	3.7%
Main Linac	22,168	435,264	50.6%	47.9%
BDS (beam)	3,130	127,357	7.1%	14.0%
BDS (service)	2,654	42,207	6.1%	4.6%
Total	43,785	909,309	100.0%	100.0%

Main Linac Shafts. Space is reserved for survey lines of sight. Figure 13.28 shows a typical cross-section through the ML tunnel.

Bored penetrations are used for process water, electrical services and laser beams.

The Damping Ring has tight radius that is achievable with a TBM and mucking system designed specifically for this application.

13.7.2.1.2 Hall, caverns, and alcoves (Ed: *figures needed for this section)*

There are underground caverns and alcoves along the tunnels, in addition to the central IR hall. Caverns are located at the base of each shaft, and alcoves provide safe havens in emergencies and also house equipment. The caverns and alcoves are sized for:

- The amount and nature of equipment to be housed: cryogenic, electrical, cooling and ventilation, water distribution, electronics, etc.
- Connecting services between access shafts and tunnels.
- Lowering, assembly, commissioning of TBMs for the excavation work (for those caverns where excavation starts or ends).

The caverns have movable steel-concrete shielding doors moving on air-pads or rails, which can be opened for equipment transfer into the beamline area.

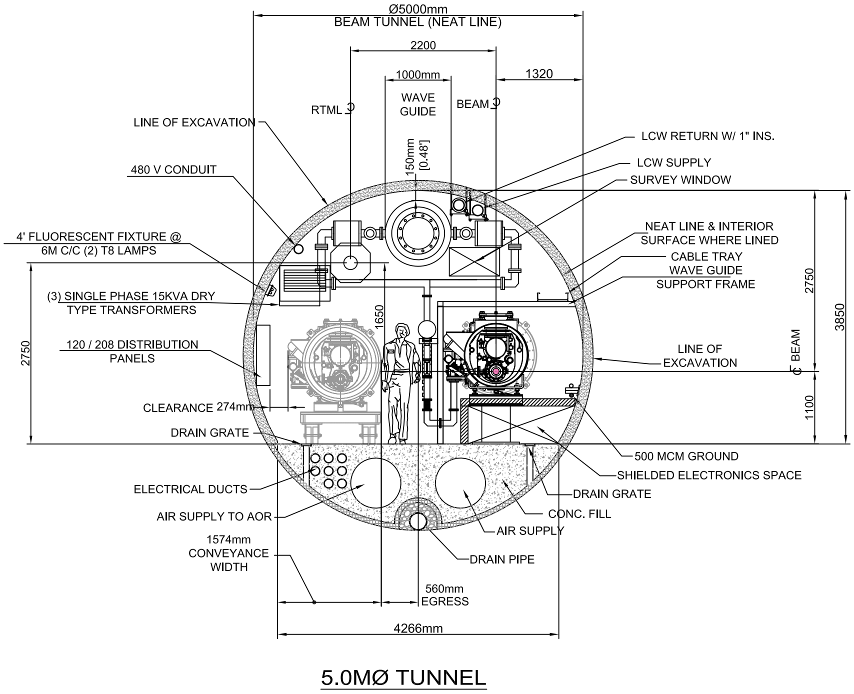


Figure 13.28: Typical ML tunnel cross section

The Interaction Hall has a garage for each detector with one 40 t crane in each garage and one in the IR hall.

13.7.2.2 Underground access

(**Ed:** *figure needed for this section?*)

There are a total of 14 vertical shafts along the linacs, two 6 m diameter shafts for the Ring to Main Linac (RTML), four 14 m diameter major equipment shafts, two 9 m diameter shafts and six smaller 6 m diameter shafts for the Main Linac (ML). The shafts allow movement of equipment and personnel, and provide accessways for services such as cooling water, potable water, compressed air, cryo-fluids, electrical supply, and controls. The over-moded waveguide also uses these shafts. Two shafts service the ML and Sources / Beam Delivery Area systems. There are two access shafts serving the Damping Ring tunnel. The 9 m diameter shafts are situated at opposite sides of the damping ring at the midpoint of the straight sections. In the Central Region there are four 1.5 m diameter shafts that supply utilities to the high power beam abort caverns. The IR Hall has an 18 m diameter shaft used for lowering major detector segments from the Assembly building at grade. There are also two 8 m diameter shafts for lowering smaller equipment into the hall, one for each detector, and two 6 m diameter shafts for utilities and personnel egress.

13.7.2.3 Surface structures

(**Ed:** *figures needed for this section)*

The Klystron Cluster RF feeds the Main Linac at 2.5-kilometer intervals. The Main Linac surface infrastructure installations are spaced every 2.5 kilometers at the head of a service shaft to the tunnel. The surface installations every 5.0 km also have cryogenic cooling plants. At the central region end of the Main Linac, there are hybrid installations where a single Klystron cluster powers the last 1.25 km of the Main Linac.

The number and size of buildings relative to each area system is listed in 13.8.

Table 13.8: Surface structures by Area systems

Source area	Qty	Area (m^2)	% Area
e^- source	0	–	0.0 %
e^+ source	1	1,140	1.5 %
Damping Ring	10	5,294	6.9%
RTML	4	1,410	1.8 %
Main Linac	80	60,200	78.1%
Minor Shaft fooprint		4 @ 3,808	
Major Shaft fooprint		6 @ 6,024	
PM-7, PM+7 fooprint		2 @ 4,408	
BDS	0	–	0.0%
IR	3	9,056	11.7%
Total	–	77,101	100.0%

13.7.3 Mechanical

13.7.3.1 Processed water

Thermal heat loads were tabulated for each area system. Design specifications were developed [3]– [12]. The ML accounts for about 60% of the total load. Tables 13.9

and 13.10 show the distribution of heat loads by component (above and below ground) and by Area System.

Table 13.9: Main Linac KCS RF Heat Load (TDR Baseline Low Power)(**Ed:** *table is way too large to fit when converted to LaTex, consider rotating it or -better- shortening the headers)*

			To Low Conductivity Water										to Chilled water	To AIR
	Quantity	Average Heat Load (KW)	Heat Load to LCW Water (KW)	Max Allowable Temperature (c)	Supply Temp (C)	Delta Temperature (C delta)	Water Flow (l / min)	gpm	Delta Temperature (F delta)	Maximum Allowable Pressure (Bar)	Typical (water) pressure drop Bar	Acceptable Temp Variation delta C	Racks Heat Load (KW)	Heat Load to Air (KW)
RF Components x (692)														
RF Charging Supply	413/ML	2.39	1.67		40	8.5	*2.84*	*0.75*	*15.23*	18	5	10	NA	0.72
Switching power supply	413/ML	5.5	3.3		35	6.25	7.6	*2.008*	*11.24*	13	5	10	NA	2.2
Filament Transformer	413/ML	0.79	0.6	60	35	0.40	20	*5.283*	*0.715*		1	n/a	NA	0.2
Marx Modulator	413/ML	5.0	3.0		35	2.14	20	*5.283*	*3.846*	10	5	n/a	NA	2.0
Klystrn Scket Tank / Gun	413/ML	0.99	0.79	60	35	1.14	10	*2.642*	*2.047*	15	1	n/a	NA	0.2
Focusing Coil (Solenoid)	413/ML	1.68	1.6	80	55	2	10	*2.642*	*4.048*	15	1	n/a	NA	0.1
Klystron Collector	413/ML	38.43	37.1	87	38 (inlet temp 25 to 63)	14	37	*9.774*	*25.94*	15	0.3	n/a	NA	1.29
Klystron Body & Windows	413/ML	3.37	3.4	40	25 to 40C	5	10	*2.642*	*8.702*	15	4.5	+ - 2.5 C	NA	
CTOs & combining Loads/circulators	2/Klstrn	11.71	9.36			6.04	22.28	5.89	*10.86*		*(80 psid)*			2.3
Relay Racks (Instrument Racks)		3.0	0	N/A	N/A	N/A		0	*N/A*	N/A	N/A	None	3	0.0
Subtotal surface RF& NonRF unit Only (for 1 RF)			60.74		Total surface RF (excluding Racks) =					69.82			3.0	9.1
COMPONENTS IN THE TUNNEL **(listed as per RF)**														
RF Components (x 584)														
RF Pipe in Shaft (shaft & bends)		1.89	1.70			10	*2.445*	*0.646*	*18*		*(80 psid)*			0.2
Relay Racks (Instrument Racks)		5	0	N/A	N/A	N/A	N/A	*N/A*	*N/A*	N/A	N/A	None	5	0.0
Main tunnel Waveguide & local Waveguide		12.23	11.62			12	*13.9*	*3.673*	*21.6*		*(80 psid)*			0.6
Distribution End Loads & Cavity Reflection loads		31.80	29			20	*20.54*	*5.427*	*36*		*(80 psid)*	*+ - 2.5 C*	0	3
Subtotal Tunnel RF& NonRF unit Only (for 1 RF)			41.94		Total tunnel RF (excluding Racks) =					45.92			5.0	4.0

There are two types of water cooling systems; The first uses a chiller to provide cool supply water (chilled water/LCW), and the second uses only the cooling tower and site ambient wet bulb dependent(**Ed:** *Huh?)* , providing warmer supply water temperature (process water/LCW). The chilled water/LCW type system is used in the Damping Ring, Interaction Region and Central Region areas (which includes e^+ source, e^- source, and BDS). This provides tight air temperature stability air in these areas. The Main Linac (ML), RTML and the Main Dump, use the process/LCW water. Figures 13.29 and 13.30 show typical schematic diagrams of the process water and chilled water support utility systems.

For both systems, the cooling tower type is a closed circuit evaporative cooler, using closed loop glycol water as is customary in cold climates. This type of tower conserves water and treatment chemicals as compared to an open tower system. All

Table 13.10: Summary of Heat Loads (MW) by Area Systems (TDR baseline)

Area Systems	load to LCW	load to Air	Conventional	Cryo (Water Load)	Total
e^- sources	1.40	0.70	0.80	0.80	3.70
e^+ sources	5.82	0.64	1.51	0.59	8.56
DR	10.92	0.73	1.79	1.45	14.89
RTML	4.16	0.76	0.68	part of ML cryo	5.59
Main Linac	43.3	8.7	5.32	32.0	89.34
BDS	9.2	1.23	3.23	0.41	14.07
Major Dumps	14		0.05		14.05
IR	0.4	0.76	0.10	2.65	3.91
Total	89.2	13.5	13.5	37.9	154

surface plants are provided with n+1 redundancy. The make-up water to the system is supplied from individual wells or municipal water supply at each surface plant.

For the ML/RTML's process water/LCW system, cooling towers provide a maximum 28.3 °C cooling water supply to the LCW heat exchangers. The heat exchanger supplies about 29.4 °C LCW to the loads. About 60% of the heat loads from the ML are located on the surface. The load-to-air component of the tunnel heat loads is minor and handled by the tunnel ventilation system. At the surface, the ML surface heat loads to air from the RF components are dissipated using ambient air ventilation systems. The HLRF for the RTML area is located in a short support tunnel adjacent to the accelerator and therefore requires fan coils for conditioning its relatively large heat load to air. The Main Dumps near the Interaction Region have a dedicated process water system.

For the Damping Ring area, tunnel fan coils use a cooler 10 °C supply water to maintain a tunnel temperature closer to the mean temperature of the magnet loads and to provide for a better air temperature stability [14]. The rest of the loads in the damping ring and central region, such as magnets, power supplies, and RF, are provided with approximately 18 °C LCW supply. The chiller system design includes a waterside economiser that would automatically provide free cooling using the cooling tower if the ambient conditions are adequate.

The main distribution of the cooling water system follows the location of the shafts [15]. There are total of nineteen surface water plants, twelve for the ML/RTML, two for the central region, two for the IR, two for the DR, and one for the main dumps.

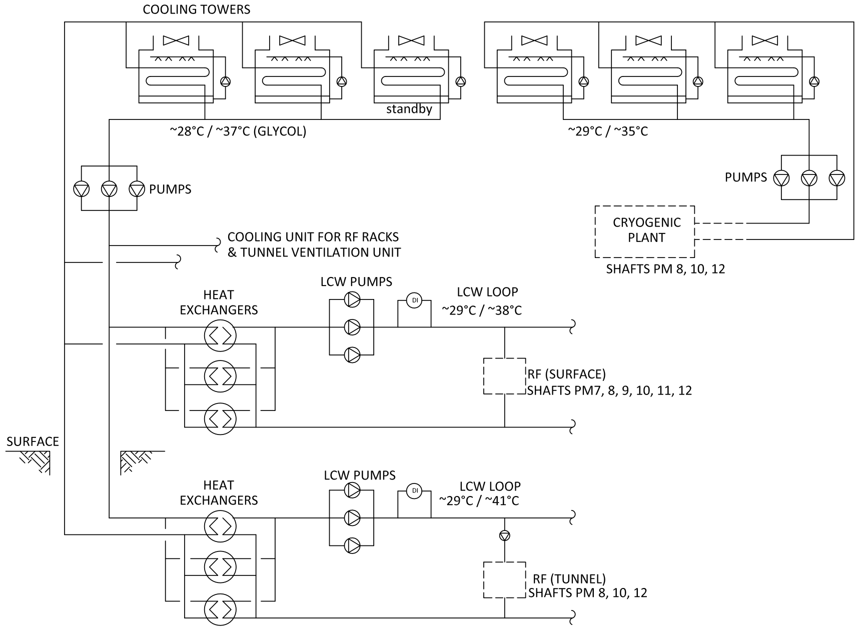


Figure 13.29: Typical process water schematic.(**Ed:** *figure quality poor - lines too thin)*

13.7.3.2 Piped utilities

Groundwater inflow and condensate drainage for all underground areas is estimated to be 21 m^3 / h / km. The total number of duplex sumps pumps required are 132 in the Main Linac, 121 in the Central Region/Interaction Region, and 32 in the Damping Ring area. Groundwater duplex lift pumps and collection tanks are provided at every major shaft location. Each groundwater lift station has three pumps, any of which can pump the entire inflow volume. Water discharge is piped up the shaft through separate and protected piping systems.

13.7.3.3 Air treatment

There are two ventilation systems, one for the Areas of Refuge (AOR) and the other for the general tunnel ventilation. Both systems have individual separate supply air ducts through the shafts, from the surface ventilation units, down to the cavern floor. They use the tunnel floor for further distribution along the length of the tunnel as well as into the AOR. Each unit is sized to 20% overcapacity to provide

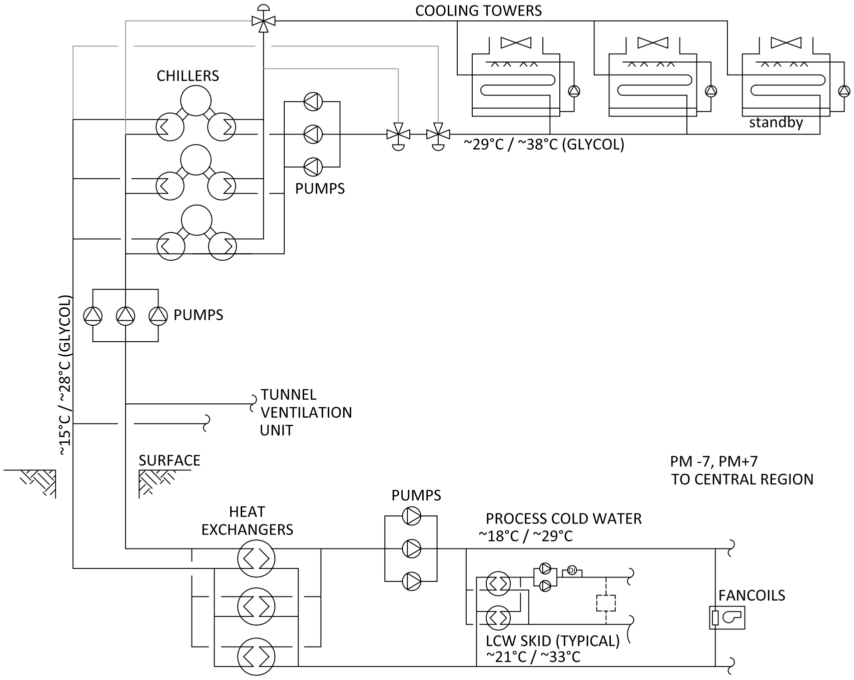


Figure 13.30: Chilled Water/LCW System at Central Region.(**Ed:** *figure quality poor - lines too thin)*

some redundancy in case one surface unit fails. The general tunnel ventilation is conditioned to provide neutral temperature dehumidified air, while the AOR ventilation unit is non-conditioned raw outside air to be used only when the AOR is occupied. Return air from the general tunnel ventilation system is ducted up from the caverns to the surface units. In general the heat is removed from the tunnel areas by separate fan coils, except in the Main Linac area where the heat load is minor and the tunnel ventilation is adequate. The tunnel ventilation provides 0.45 m/s air speed and an air change rate of approximately 2 per hour. The temperature in the tunnels is a maximum of 40 °C in the ML/RTML tunnel area and 29 °C in the central region, Damping Ring, IR, and service tunnels/caverns. Figure 13.31 shows a typical schematic diagram of the ventilation system.

13.7.4 Electrical

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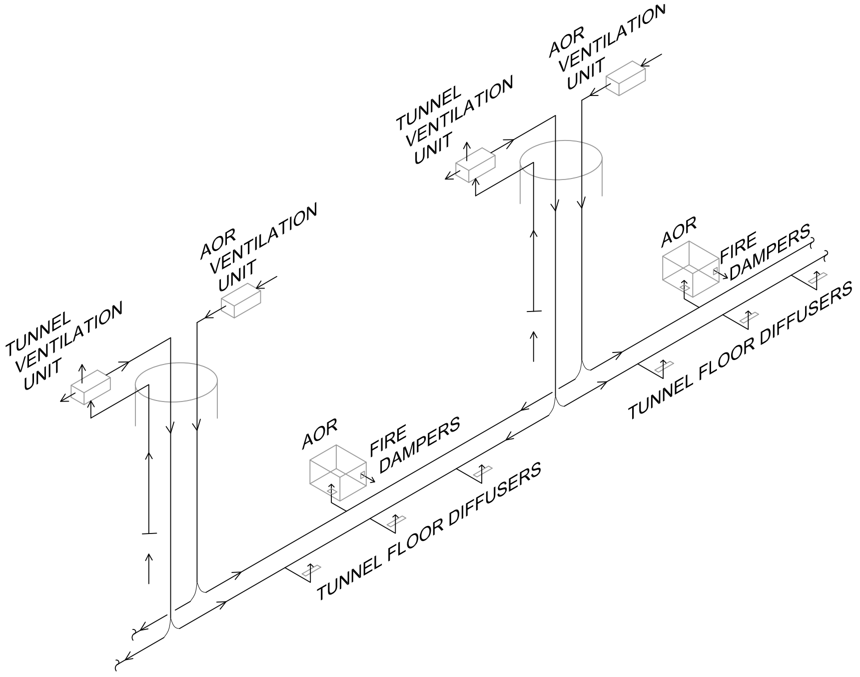


Figure 13.31: Typical Ventilation Diagram

Electrical load tables were compiled for each area and the systems designed. The Main Linac (ML) area 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 (pf) value used for equipment sizing is the actual expected, if given, or a 90% pf for all other equipment. Table 13.11 shows a summary of the power loads distributed by component and Area System.

The electrical power supply system is divided into major systems by function:

- Supply – 345 kV large overhead interconnect with the local Utility transmission grid.
- Transmission – 69 kV and 34.5 kV main feeders serving local substations.
- Medium Voltage Distribution – 34.5 kV distribution lines from local substations to service transformers distributed throughout the project.

Table 13.11: Summary of Power Loads (MW) by Area Systems (TDR baseline)

Area System	RF Power	RF Racks	NC magnets & Power supplies	Cryo	Conventional		Total
					Normal load	Emerg load	
e^- source	1.28	0.73	0.80	1.02	0.16	4.08	
e^+ source	1.39	4.94	0.59	2.19	0.35	9.56	
Damping Ring	8.67	0.09	2.97	1.45	1.84	0.14	15.08
RTML	4.76	0.09	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

- Medium Voltage Standby Power Distribution – 4.16 kV distribution lines from generators to dedicated power transformers that serve standby loads.

- Low Voltage Distribution – 480 and 208/120 V local distribution lines that directly serve loads.

- Low Voltage Standby Power Distribution - 480 and 208/120 V local distribution lines that directly serve standby power loads.

The Supply system consists of a 345 kV overhead line from the local Utility grid to the central campus substation. The interconnect point with the local utility serves as the ownership demarcation point with a switching device and revenue metering. The local Utility has a switching device at this point to manage services to the project. All loads and losses beyond this point are included in the electrical power bill. Due to the large power requirements, the electrical system is designed to be independent and standalone from the local electrical utility infrastructure at the highest possible level.

The electrical power system for the project originates at the Central Campus Substation. The Central Campus Substation includes two 345 kV to 69 kV transformers and two 345 kV to 34.5 kV transformers. Each transformer serves a specific part of the project through switchgear. The 69 kV switchgear is outdoor rated, SF6 gas insulated switchgear (GIS) that enables a compact reliable installation at this voltage class. The 34.5 kV switchgear type is enclosed bus with vacuum circuit breakers that provide a compact reliable installation at this voltage class. Figure 13.32 illustrates the Central Campus Substation.

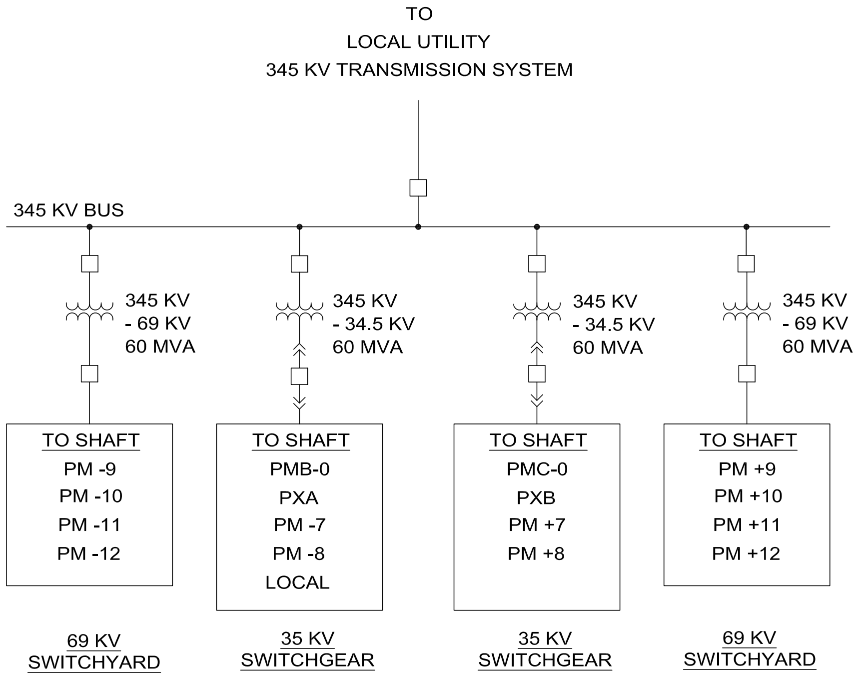


Figure 13.32: Electrical transmission system.

The 69 kV and 34.5 kV transmission system provides the required power to each local substation or switching station generally located at the top of each shaft. The system is a combination of substations, switching stations, 69 kV feeder lines and 34.5 kV feeder lines. The architecture of the system is a single feed radial configuration extending from the central campus to the ends of the accelerator tunnels and the far side of the Damping Ring.

The 34.5 kV transmission feeders originating in the Central Substation serve the Damping Ring and near shafts, PM-7, PM+7, PM-8 and PM+8 local substations. The local Central Region loads are served directly from the substation switchgear while 34.5 kV feeders are routed through the tunnel to other shafts. The feeder that serves shafts PM-7 and PM-8 extends down the tunnel to shaft PM-7 where 34.5 kV switchgear provides service to local Medium Voltage Distribution and a feed through to shaft PM-8 for local distribution. Similarly a feeder configuration is included for

PM+7 and PM+8. The 34.5 kV transmission voltage to these locations enables direct Medium Voltage Distribution through switchgear without the installation of local substation transformers at the Damping Ring, PM+/-7 and PM+/-8.

The 69 kV transmission feeders originating in the Central Substation serve the shafts PM+/- 9 to the end of the tunnels. The 69 kV voltage level is used to minimize the number and size of conductors and conduits installed in the tunnel. The 69 kV feeders are extended from the Central Substation GIS to shafts PM+/-9 and PM+/-11. 69 kV to 34.5 kV substations are located at each of these shafts to provide local Medium Voltage Distribution and 34.5 kV feed to subsequent shafts, PM+/-10 and PM+/-12. No substation transformers are required at shafts PM+/-10 and PM+/-12.

The Medium Voltage Distribution system provides power to each distribution transformer that serves a load in the tunnel or on the surface. The distribution feeder system is a radial configuration from the local substation switchgear to the distribution transformers. On the surface, transformers serve specific loads such as RF Units, Cryogenics or Conventional Facilities. In the tunnel, a distribution transformer is located in the base cavern to serve all conventional loads. The technical loads in the central region that include a service tunnel are served by a separate local transformer. Figure 13.33 illustrates a 34.5 kV distribution switchgear that serves both local loads and provides the origin of the transmission feeders to other shaft substations.

Standby power generation is provided at each shaft location to support life safety facilities when normal power is not available. The standby power distribution system automatically generates electricity for selected facilities when called upon using diesel generators. The generators are rated at 4.16 kV and sized for the load served. The 4.16 kV voltage is needed due to the length of the distribution feeders. On the surface and in the tunnel, a dedicated standby power transformer is provided to serve the standby power loads.

The electrical lines are installed in the underground tunnels and enclosures in conduits that are either in concrete encased duct banks or embedded in the tunnel floor and routed up to the surface at each shaft. Cable installation and splicing is accommodated with vaults spaced at approximately 522 m along the length of the main tunnel.

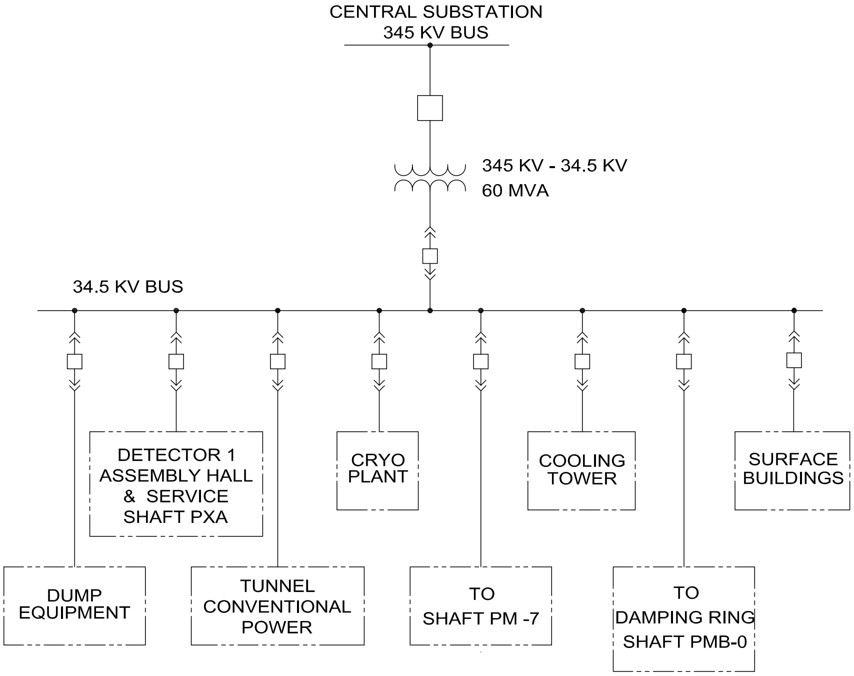


Figure 13.33: Central Region 35 kV Switchgear One Line Diagram

13.7.5 Life safety and egress

The life safety requirements and fire protection systems for the single tunnel design concept are based upon the National Fire Protection Association (NFPA) 520, Standard for Subterranean Spaces, 2005 Edition. In addition, Hughes Associates, Inc. was retained to assess the feasibility of the single tunnel design by analyzing different fire scenarios in the beam tunnel and damping ring. A fire analysis of the single tunnel portions of the ILC installation was conducted using the Fire Dynamics Simulator (FDS) computational fluid dynamics model program developed by USA National Institute of Standards. Models of different fire sizes were constructed for the Main Linac Tunnel, Base Caverns, and Damping Ring. Anticipated combustible fuel loadings in the single tunnels were evaluated and it was determined that pool/spill fire scenarios involving transformer oil were the most demanding fire scenarios. The following table summarizes fire size limitations for various size tunnels based on spill area, rates and volumes.

Table 13.12: Summary of Tunnel Fire Modeling Results

Tunnel type	Tunnel diameter	Limiting fire size	Confined spill area	Continuous spill rate		Unconfined spill volume	
	(m)	(kW)	(m^2)	(gpm)	(l/min)	(gal)	(l)
Main Linac/ Straight Damping Ring	4.50	750.00	0.80	0.34	1.28	0.33	1.25
	5.00	1,000.00	1.00	0.45	1.70	0.41	1.57
	5.50	1,100.00	1.10	0.49	1.87	0.45	1.69
	6.50	1,500.00	1.40	0.67	2.55	0.57	2.17
Base cavern	4.50	3,000.00	2.40	1.35	5.10	1.02	3.86
	5.00	4,000.00	3.00	1.80	6.81	1.31	4.95
	5.50	4,500.00	3.30	2.02	7.66	1.45	5.48
	6.50	6,000.00	3.60	2.70	10.21	1.87	7.08
Curved Damping Ring	4.50	2,500.00	2.00	1.12	4.25	0.87	3.31
	5.00	3,250.00	2.50	1.46	5.53	1.09	4.13
	5.50	4,000.00	3.00	1.80	6.81	1.31	4.95
	6.50	5,000.00	3.60	2.25	8.51	1.59	6.02

The findings support the single tunnel concept and prove that the life safety requirements and fire protection system requirements of NFPA 520 will allow occupants in the single tunnel portions of the ILC to evacuate safely during a fire, provided that the maximum anticipated fire size in a tunnel can be restricted to the limiting fire sizes for each tunnel type and diameter established in the analysis. In addition, the analysis concluded that it is not necessary for mechanical systems in the tunnel to shut down during a fire event, provided air velocities supplied to the fire are less than 1 m/s. (**Author:** *We should probably list what this velocity applies to. (I assume air)*)

13.7.5.1 Personnel egress

The main linac is housed in a single tunnel with vertical shafts spaced approximately 2000 m apart which provide access to the surface. At the base of each access shaft is a cavern that contains oil-filled electrical equipment, water pumps, motors and other utility equipment. This equipment has the highest risk for fire. The prevailing codes require the containment of such areas through the use of fire rated walls and doors. In addition, the elevators located in each shaft are also isolated by fire rated walls and doors. Once these areas are properly isolated, the main linac (or damping ring) tunnel can be used for personnel travel to the shaft exit in the event of an emergency incident. Due to the overall tunnel length, it is also required to have a fire protected area of refuge (AOR) located at the midpoint between shafts to provide an intermediate safe area for injured personnel or to await emergency response assistance. In areas where a service tunnel is located adjacent to the main tunnel, such as the RTML and BDS, crossover labyrinths are provided for passage between the two tunnels. These crossover labyrinths are located such that the travel distance to the crossover does not exceed 122 m (400-feet) from any point in either tunnel. The crossover labyrinths are separated by 2 h fire rated construction. The damping ring is an extension of the single portion of the tunnel and is provided with two vertical exists. These exits are separated from the common space by 2 h fire rated construction. Provisions for the required emergency fixtures are included:

- Emergency lighting
- Illuminated exit signage
- Illuminated exist direction signs
- A check in and check out system will be established

13.7.5.2 Suppression

Automatic sprinkler protection is provided throughout the facility. It is a class I standpipe system with 2-1/2-inch fire department hose valves spaced approximately 100 m apart. Portable fire extinguishers are also provided.

13.7.5.3 Fire detection

Addressable fire detection and voice alarm is provided. Manual pull stations are spaced approximately 400 feet**(Ed:** *convert in meters)* apart. Smoke detection is provided at caverns and other sensitive areas. A voice/alarm system is capable of transmitting voice instructions from the fire command station located at the surface buildings. A two-way fire department communication system is provided and operated from the Fire Command Station. The two-way communication jacks are spaced 130 m apart.

13.8 Handling equipment

13.8.1 Introduction

This section covers the handling equipment used for on-site transport and installation of components. The on-site handling and transport operations start with unloading of components following delivery by their supplier to the site and finish when the components are installed in their final positions in the accelerator tunnels and service buildings.

ILC Handling equipment can be split into two main categories:

- "Installed handling equipment" that is permanently installed in buildings or underground structures, such as cranes, elevators, hoists, and the external gantry used to lower experiment modules to the underground area.
- "Mobile handling equipment" that can move between buildings or underground structures, such as road transport and handling equipment, industrial lift trucks, tractors and trailers,and custom-designed vehicles for transport and installation of equipment underground.

For the underground transport and installation of cryomodules and magnets, special equipment is needed so as to fit within the tunnel cross section, taking account of cost and installation timescale considerations. The mobile equipment used on the surface and in the tunnels is essentially the same for US, European and Asian sites.

Equipment used to move detector components before lowering is not discusseded in this section. The US and European handling equipment solutions that are based on the use of vertical access shafts are described. Inclined access tunnels are used in the Asian design. In this case, a fleet of goods and passenger vehicles is used for equipment and personnel transit between the surface and underground areas. The fleet is defined and operated to ensure adequate throughput as required by the installation schedule and also to ensure safe exit for personnel working underground in the event of fire or accident. Vehicles equipped with internal combustion engines are used for the inclined access tunnels; these are not suitable for use in the rest of the underground areas. To allow transfer of equipment from the inclined tunnel access vehicles to the tunnel transport and installation vehicles, junction caverns equipped with overhead travelling cranes provide the interface between the underground accelerator areas and the sloping access tunnels.

13.8.2 Items to be transported

Handling is required for: cryomodules,magnets,RF equipment,vacuum pipes, beam dumps(**Ed:** *what does this mean?)* cooling and ventilation equipment,electrical cables and cable trays,and racks.

13.8.3 Transport operations

13.8.3.1 Initial delivery to site

Delivery of equipment to site is covered by the supply contracts for each item of equipment. This means delivery to assembly halls, storage areas or tunnel access points as appropriate.

13.8.3.2 Surface transport and handling on and between sites

Surface transport operations include transfers inside and between buildings on the main laboratory site as well as transfers between the main laboratory site and the tunnel access points. These operations are carried out using a fleet of road transport vehicles. Vehicle unloading is carried out by industrial lift trucks or overhead travelling cranes.

13.8.3.3 Transfer between surface and underground via vertical access shafts

Lowering of equipment from the surface to the underground areas is carried out via vertical access shafts equipped with elevators and overhead travelling cranes. Shafts of different diameters are used along the length of the accelerator; four 14 m diameter shafts are available for lowering of cryomodules.

The surface buildings above the access shafts are equipped with overhead travelling cranes with sufficient lift heights to lower equipment to the caverns at the base of the shafts via handling openings reserved in the shaft cross section. In addition goods/personnel lifts allow personnel access and are also used to lower equipment. The cross section of a 9 m machine access shaft with crane handling opening and lift shaft (European site version) is shown in Fig. 13.34.

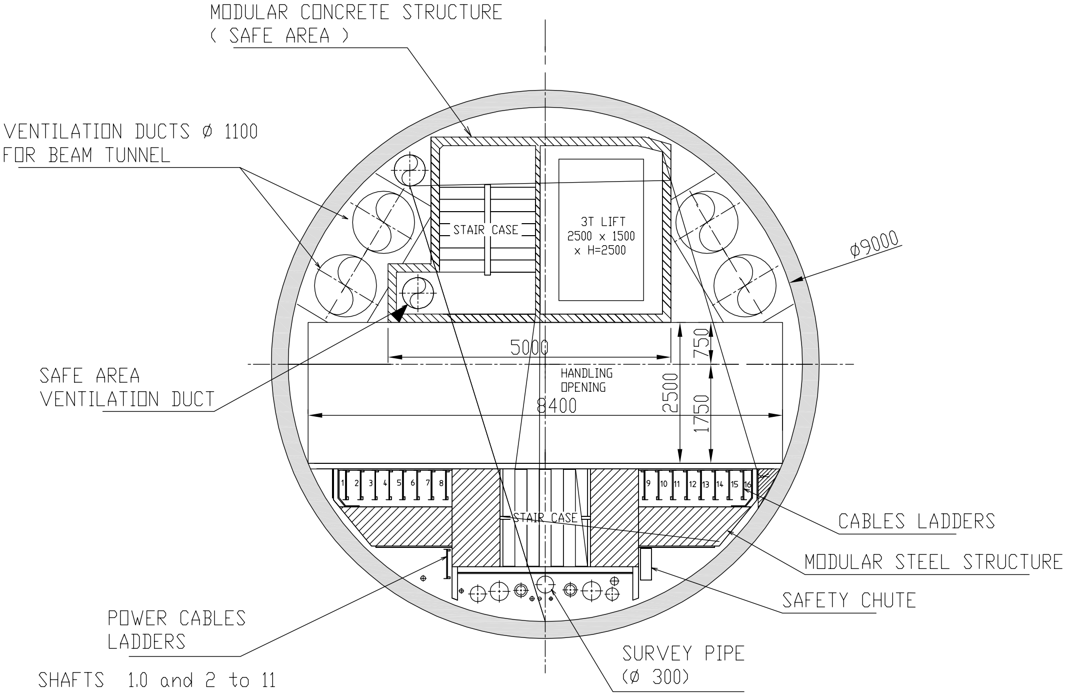


Figure 13.34: Cross section of access shaft

13.8.4 Installed handling equipment

13.8.4.1 Elevators

Elevators meeting standards for personnel use are installed for personnel and goods transfer between the surface and underground areas and also within the underground areas and surface buildings. The elevators are listed in Table 13.13.

13.8.4.2 Cranes

13.8.4.2.1 Shaft transfer and underground area cranes For US and European sites the transfer of heavy loads between the surface and the underground areas is carried out using overhead travelling cranes installed in the surface buildings above shafts. Cranes are used for handling of loads underground in the experimental detector caverns and interaction region as well as in the beam dump and positron source caverns. Table 13.14 lists the cranes for transfer from surface to underground and for underground handling.

Table 13.13: Elevators(**Ed:** *question mark in row 5 - fix)*

Location		Area			
Shaft Diameter	Shaft/ location	DR	RTML	Main Linac	Experiment
14m	PM-12, PM-8, PM+8, PM+12			4 x 2.8 t	
9m	PM-10, PM+10			2 x 2.8 t	
6m	PM-13, PM-11, PM-9, PM-7, PM+7, PM+9, PM+11, PM+13		2 x 2.8 t	6 x 2.8 t	
9m	PMB-0, PMC- 0	2 x 2.8 t			
6m	PZB-0, PZA-0 ?				2 x 2.8 t
	Control room				2 x 1.6 t
	Detector caverns				2 x 1.6t

13.8.4.3 Service building cranes

In addition to the cranes installed in surface buildings above access shafts, cranes are installed in the service buildings to carry out installation and maintenance of plant. These cranes are listed in Table 13.15.

13.8.4.4 Hoists

Hoists are installed in surface buildings and underground areas for various installation and maintenance activities; they are summarised in Table 13.16.

13.8.4.5 External gantry used to lower experiment modules to the underground area

An external gantry of 4000 t capacity is used to lower assembled detector modules from the surface to underground. This gantry is rented from an industrial supplier for the period scheduled for lowering the modules; the supply contract includes its assembly, operation then dismantling and removal from site.

13.8.5 Mobile handling equipment

13.8.5.1 Underground transport and handling

13.8.5.1.1 Schedule and space considerations Initially the full width of the accelerator tunnels are available for installation of services, allowing the use of stan-

Table 13.14: Cranes for surface service building(**Ed:** *question mark in table - fix)*

Location		Area					
Shaft Diameter	Shaft/ cavern	e^+ source	DR	RTML	Main Linac	BDS	Experiment
14 m	PM-12, PM-8, PM+8, PM+12				4 x 20 t		
9 m	PM-10, PM+10				2 x 20 t		
6 m	PM-13, PM-11, PM-9, PM-7, PM+7, PM+9, PM+11, PM+13			2 x 20 t	6 x 20 t		
9 m	PMB-0, PMC-0		2 x 20 t				
6 m	PZB-0, PZA-0						
18 m	PX-0					1 x 4000 t 2 x 400 t (40 t aux.)	
10 m /8 m	PX-A, PX-B						2 x 20 t (not 40t?)
	Detector caverns						2 x 40 t
	Interaction region						1 x 40 t
	Beam dumps					4 x 5 t	
	e^+ source	1 x 20 t					

dard industrial lift trucks, tractors and trailers. The available space for transport narrows once the beam-line equipment starts to be installed. For tunnel construction cost reasons the transport passage is kept to a minimum; this means that cryomodule transport vehicles, for instance, are not able to pass each other in the tunnel.

13.8.5.1.2 Cryomodules The space required for module transport and installation in the tunnel has a major influence on the main linac tunnel cross section. The large number of cryomodules to be transported and installed means that it is important to optimise the whole sequence of cryomodule transport to allow rapid transport and installation.

The cryomodule transport vehicle design minimises the width of the reserved transport volume. It is capable of transport along the tunnel as well as transfer from the transport zone onto the support jacks. The vehicle (Figure 13.35) is based on that used to install conventional magnets for the LHC.The vehicles are equipped with an automatic guidance system. The operator is required to ensure that the

Table 13.15: Cranes in surface service buildings and for underground hand ling.

Service buildings	Area			
	DR	RTML	Main Linac	Detectors
Cooling towers	2		12	1
Cooling ventilation	2		12	1 x 15 t
Cryo compressors	1		6	1
Klystron cluster			12 x 10 t	

Table 13.16: Hoists

Service/ underground	Area				
	DR	RTML	Main Linac	Detectors	
Surface	2 x 5 t	2 x 5 t	12 x 5 t		4 x 5 t
Underground	2 x 5 t	2 x 5 t	12 x 5 t	6 x 5 t	6 x 5 t

floor is clear of personnel and equipment. The vehicle can be configured for different loads and can therefore also be used for transport of other items.

Although module installation logistics aims for sequential installation, the installation process allows installation of cryomodules between two previously installed cryomodules in the event of supply delays or if sorting of modules is required. In addition the system is able to remove a previously installed cryomodule if major repairs are needed.

The interconnections between cryomodules are installed after the cryomodules have been positioned on their floor supports – this gives a clearance between modules of over 150 mm during their transfer onto their supports which allows rapid lateral transfer under manual control with minimum risk of damage to the adjacent cryomodule.(**Ed:** *this paragraph belongs in cryomodule chapter)*

The cryomodule design includes lifting points and support points to allow the whole sequence of transport and handling operations. These are needed during the phases of module assembly, testing, storage, road transport to access points, lowering, tunnel transport and installation. The cryomodule design includes the transport restraints and special lifting beams used when handling fully assembled cryomodules during the installation process.(**Ed:** *this paragraph belongs in cryomodule chapter)*

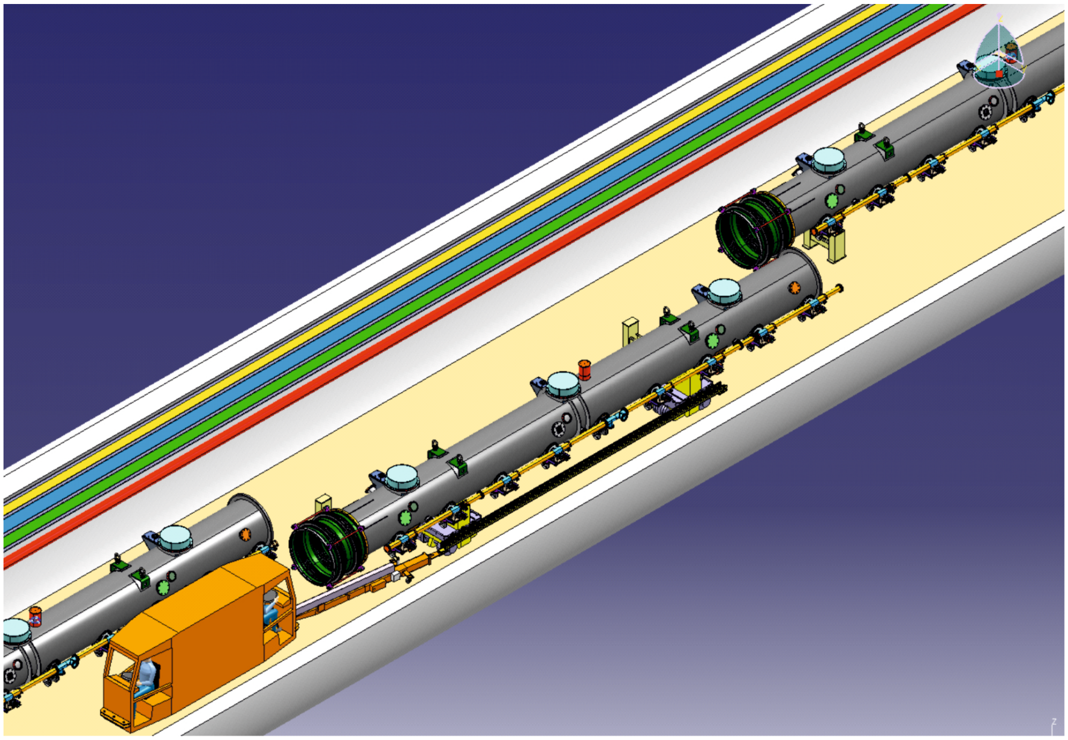


Figure 13.35: Cryomodule transport vehicle during transfer onto supports (Case shown is installation between two previously installed cryomodules)

13.8.5.1.3 Magnets Specially designed vehicles (Figure 13.36) are used for their transport along the tunnel followed by their installation. The use of vehicles combining transport, lifting and transfer avoids the need to transfer the load between different items of equipment and results in optimised installation times.

13.8.5.1.4 RF equipment RF equipment installation requires transport along the tunnel followed by precise positioning at a range of heights. The solution is to use an adaptation of the magnet transport and installation vehicle.

13.8.5.1.5 Other accelerator equipment Standard industrial handling equipment such as forklift trucks, electrical tractors and trailers are used to transport and install equipment other than cryomodules, magnets and RF in the tunnel. Where optimal this installation is carried out before cryomodule and magnet installation.

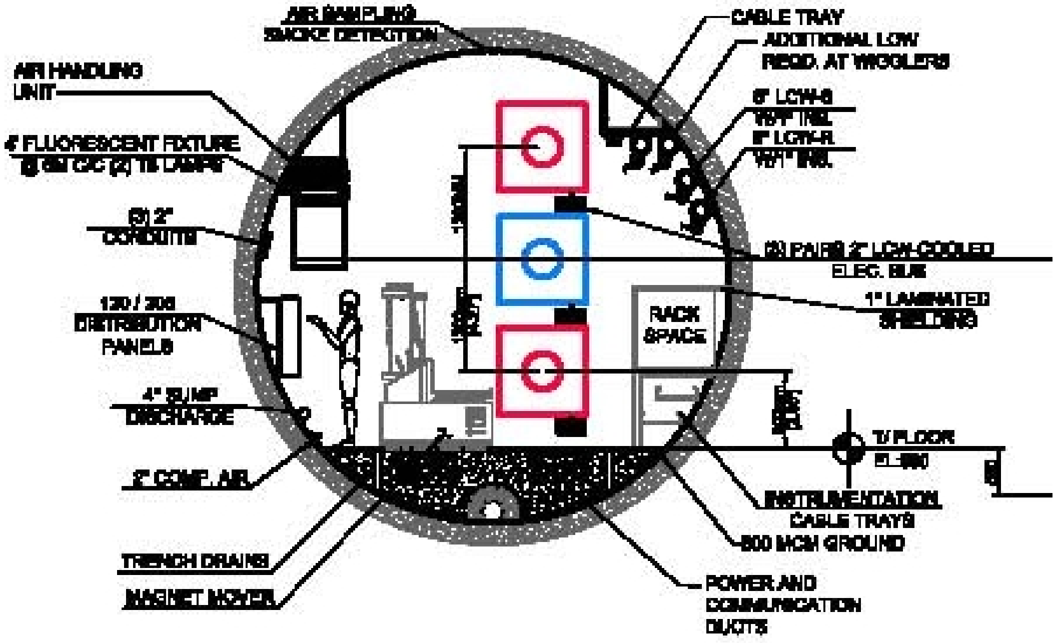


Figure 13.36: Special vehicle for magnet installation – shown in damping rings tunnel.(**Ed:** *figure quality poor)*

13.8.5.1.6 Personnel transport Personnel transport in the underground areas is by means of small electrical tractors or bicycles.

13.8.5.2 Surface transport and handling equipment

Standard road-going trucks and trailers are used for surface transport between sites. Standard industrial handling equipment such as forklift trucks, are used for material handling where it is not feasible to use overhead travelling cranes.

13.9 Alignment and survey

(**Ed:** *this whole unedited section could be copied to a note and referred to)* .

13.9.1 Introduction

The ILC requires very tight tolerances in absolute and relative accuracy for the positioning of its components. These tolerances come mainly from optics requirements, as well as aperture and mechanical considerations. The errors of misalignment of the fiducials concerning components located in different areas are shown in Table 13.17. The methods proposed to reach these requirements as well as the different steps of alignment are described in detail in the following chapters.

Table 13.17: Components and required alignment tolerances.

Area	(km)	Nb of beam	Error of misalignment on the fiducials (1σ)
e^- source	2.3	1	0.1 mm rms over 150 m
e^+ source	3.3	1	0.1 mm rms over 150 m
2 DRs	6.6	2	0.1 mm rms over 150 m
RTML	1.7	1	0.1 mm rms over 150 m
Main linac	23.9	1	0.2 mm rms over 600 m
BDS	6.5	1	0.02 mm rms over 200 m

13.9.2 Reference and coordinate systems

Reference and coordinate systems for the positioning of components need to be defined. The reference system is a local ellipsoid which fits the earth in the middle of the site area coupled with a geoid (Fig. 13.37). Measurements taken with survey instruments are linked to this Geoid.

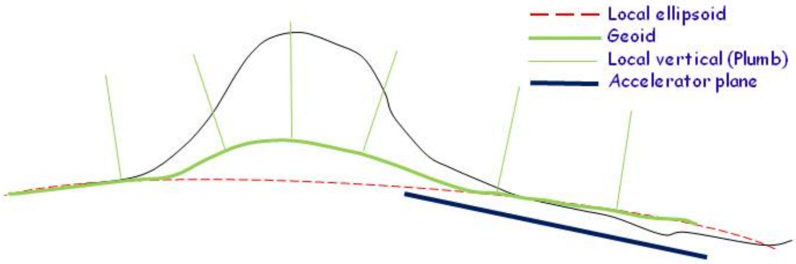


Figure 13.37: The Geoid model at CERN

Also, a Cartesian XYZ co-ordinate system has be to defined as well as an H (elevation) co-ordinate, calculated from the geoid parameters. The co-ordinates of the theoretical beam lines have to be calculated by optics software (e.g., MADx) and given in this Cartesian co-ordinate system.

13.9.3 Geodesy and networks

13.9.3.1 From surface to underground

The surface network comprises monuments, installed close to each pit, solidly anchored to the earth by means of concrete works, forming a very well defined basic framework from which the links to reference system can be established. It will also be used for regular checks and eventual extension of the project. The determination of the co-ordinates of these monuments is done by very accurate trilateration, leveling measurements and by GPS measurements (when possible). The accuracy of these network points has to be of order 1 mm. These reference points will be transferred from the surface to the tunnel through pits, using a combination of 3D triangulation and trilateration coupled with angular measurements w.r.t vertical plumb wires (Fig. 13.38). These methods were validated in an LHC pit with a depth of 65 m in 2010, where a precision of 0.1 mm and accuracy of 0.5 mm was reached.

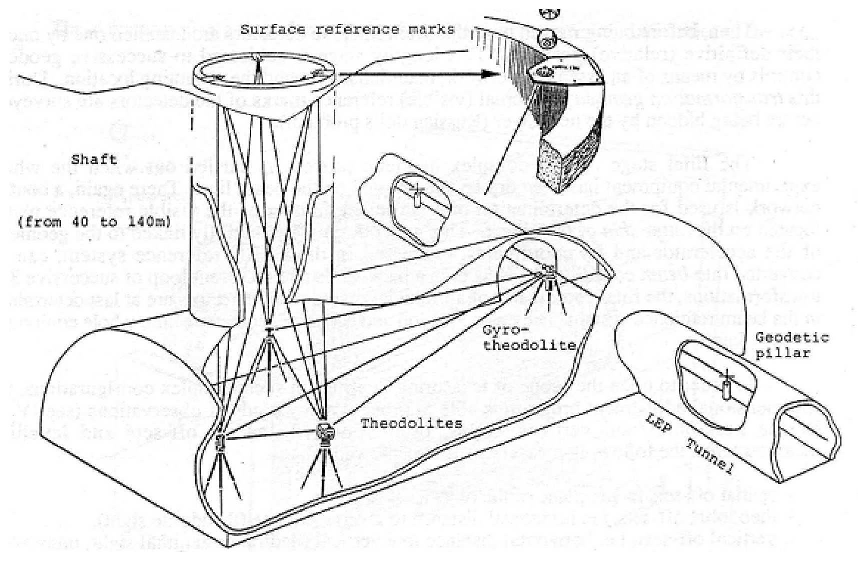


Figure 13.38: Transfer from surface to underground network

13.9.3.2 Underground networks

Underground networks will consist of dense arrays of monuments, regularly spaced all along the beam lines, as well as in stations in the main areas. 20 deep leveling references will be distributed in the tunnels. These vertical references in invar will be sealed on stable rocks. Leveling traverse will be linked to these deep leveling references which are considered to be stable over time.

13.9.4 Component Metrology

The fiducialisation of each component consists of measuring its reference axis (in our case the mechanical axis), with respect to external fiducials (at least 3 or 2 plus a roll angle reference surface). When the component is in place with its reference axis no longer accessible, it can be positioned using the external fiducials (Fig. 13.39). The fiducialisation error has been assumed to 0.1 mm r.m.s., except for the BDS, where it is 0.05 mm r.m.s. Depending on the accuracy needed, several means can be proposed: mechanical measurements using gauges could be sufficient for warm components; laser tracker measurements when requirements are of the order of 0.1 mm rms; and CMM measurements for smaller components and where the required accuracy is of the order of 0.05 mm rms.

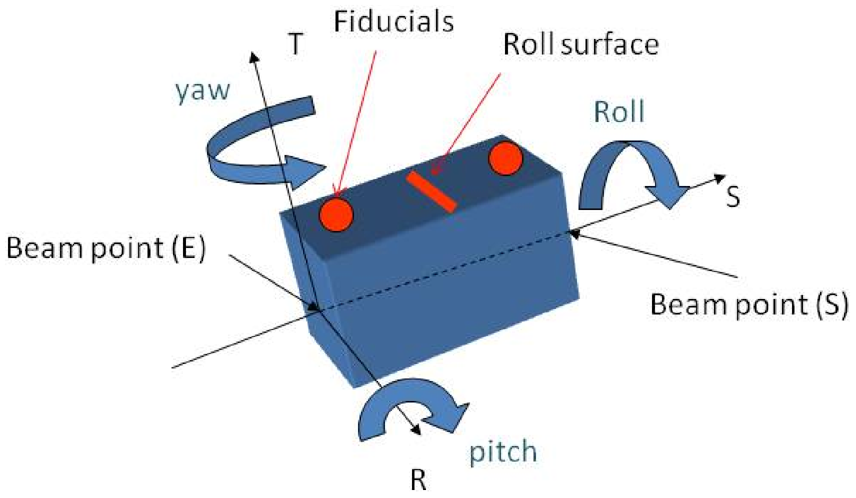


Figure 13.39: Magnet and fiducials

For cryo-assemblies the link between the reference axis under warm and cold conditions will have to be taken into account.

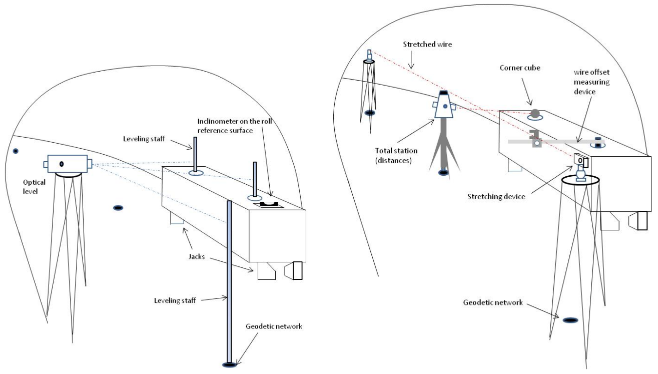
13.9.5 Component Alignment

For all areas, except the BDS and main linac, the requirements are nearly the same as for the LHC and SPS. Consequently, the same means and methods are proposed. The main linac and BDS requirements are tighter.

13.9.5.1 Systems other than the main linac and BDS

The first step is etting up markers using the geodetic underground network. The positions of the jacks supporting the components will be drawn on the floor with an accuracy of the center of the mark of ±3 mm. This phase is also very useful for installation of the services. This operation will be realized with 3D polar measurements performed using stations (Fig. 13.40).

The second step consists in aligning all the supporting systems or the jack themselves with respect to the geodetic network. The third step comprises individual alignment of the components or their supports/cryostats onto their theoretical position using the geodetic network, followed by a local 'smoothing' over 150 m to reach a relative accuracy of 0.2 mm rms on the fiducials. This second phase allows the interconnection of the components.



(a) (b)

Figure 13.40: First alignment of a magnet in vertical (a) and horizontal (b)(**Ed:** *could cut this figure)*

The last step is the final smoothing. The magnets are finally positioned around a mean trend curve contained within the envelope of maximum errors (Fig. 13.41). The relative position of the components with respect to the trend curve shall be achieved with an accuracy better than 0.1 mm (1σ). This operation needs to be performed shortly before first beam.

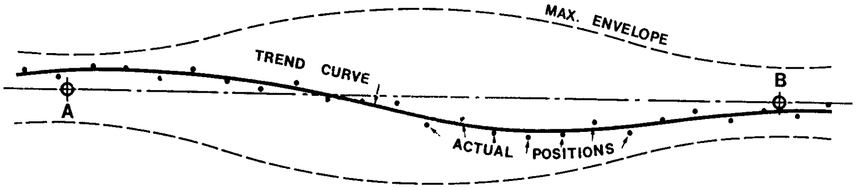


Figure 13.41: Position of the components around the trend curve

13.9.5.2 Main linac and BDS

The alignment requirements for the main linac and BDS cannot be fulfilled by standard survey means. In addition, a very good determination of the geodetic network would not be helpful for the smoothing. In both cases it is proposed to equip the components or their associated supports/cryostats with 2 Wire Positioning Sensors (WPS) providing radial and vertical offsets with respect to a stretched wire considered as the reference of alignment, and 3 Hydrostatic Levelling Sensors (HLS) providing vertical offset with respect to a water surface. These sensors will allow the determination of the position of the components according to 5 degrees of freedom (2 translations: vertical and radial, and 3 rotations) with redundancy. Two parallel lines of overlapping wires would be implemented, with wires stretched over a length of more than 300 m (see Fig. 13.42).

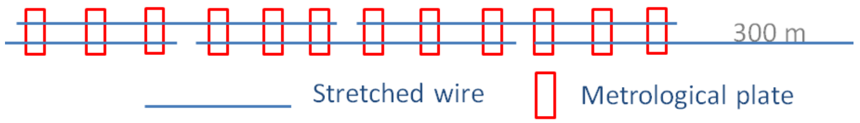


Figure 13.42: Overlapping stretched wires

To reach and maintain the positioning tolerances of the BDS located on each side of the IR Hall, an additional straight reference line will be set-up as close as possible to the components. It will be housed in a survey gallery parallel to the machine tunnel and crossing the IR Hall. This set-up will also provide the alignment of detectors with a machine reference.

13.9.6 As-built measurements and integration

Laser scanner measurements will allow 3D as-built control of infrastructures and installations

13.9.7 Metrology for the detectors and experimental area infrastructures

As built measurements of the experimental area infrastructures will be performed as soon as civil engineering works are finished, and at different stages of the installation in order to avoid interferences and ensure that all technical systems are installed correctly. A geodetic network will be installed at each floor level of the experimental cavern and will be re-determined regularly. During the period of installation, quality controls, fiducialisation and determination of the position (with respect to the geodetic network) of the components and of their assemblies will be performed. Photogrammetry can also be used for measurements of the detectors.

In push-pull mode, a method will have to be developed in order to guarantee detector re-alignment.Alignment references from the tunnel geometry will be needed.

13.9.8 Software, database and informatics

A survey database will have to be implemented in order to store the theoretical 3D definition of the machine in the 3D coordinate system at the beam level, as well as the real position of the components of the machine. The database shall also include the theoretical coordinates of all the fiducials, of the geodetic network, the geometrical measurements performed and the results of their processing. A user interface will be developed for an easy access of the data and use of calculation algorithms.

13.10 Installation

13.10.1 Overview

The baseline ILC covers a large geographical area over 31 linear kilometers long which includes a complex network of about 44 km of underground tunnels at the depth of approximately 100m and associate surface buildings. These tunnels and the associated buildings provides housing and functional environmental requirements for all of the technical equipment needed to operate the ILC machine, including but not limited to the e^-/e^+ source, e^-/e^+ damping rings, 5 GeV low-emittance transport beam lines, Main Linacs, beam delivery section and interaction region to the high powered beam dumps. In all, this requires the installation of ∼1,840 Cryomodules, over 11,130 magnets and approximately 480 high level RF stations. An overall schematic layout of the ILC is shown in Fig. 13.43.

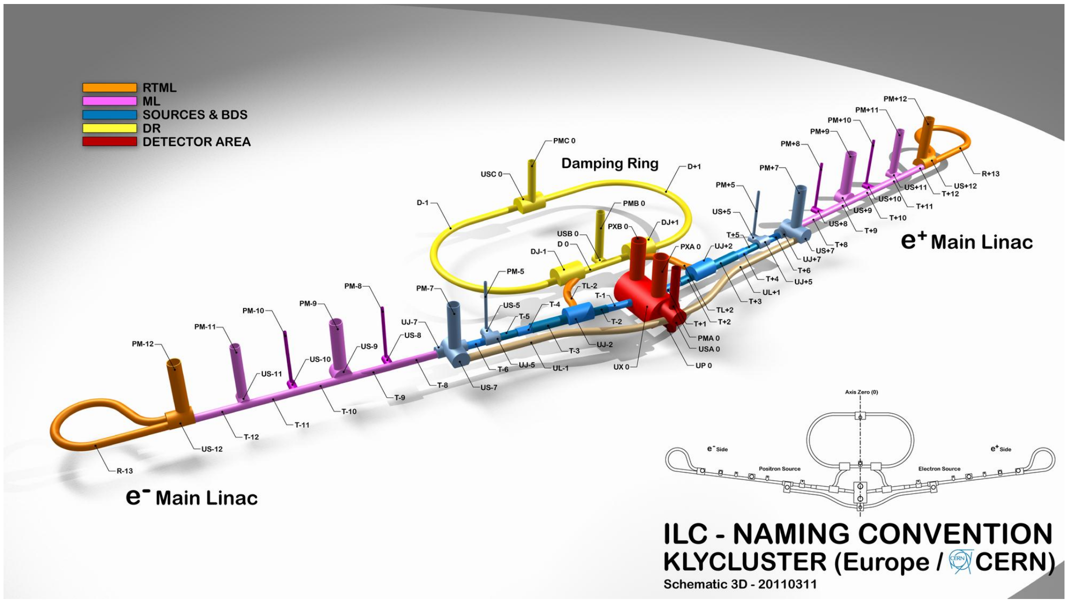


Figure 13.43: Schematic Layout of ILC(**Ed:** *surely this figure will have appeared before?)*

13.10.2 Scope

The installation consists of all activities required to prepare, coordinate, integrate, and execute a detailed plan for the complete installation of the ILC Technical Systems Components as well as associated site-wide logistics. It includes all labor, materials and equipment required to receive, transport, situate, affix, accurately position, interconnect, integrate, and checkout all components and hardware from a central storage or subassembly facility to its operational location within the Beam and Service tunnels as well as the surface service buildings where applicable. The premise is that installation group receives fully tested assemblies certified for installation. It does not include fabrication, assembly, component quality control and commissioning. It also does not include the basic utilities provided by conventional facilities, such as ventilation, air conditioning, fire prevention, high voltage electrical, chilled water and low-conductivity water distribution.

13.10.3 Methodology

For the TDR, the RDR installation methodology and procedure is followed. The installation WBS is broken down into two major level-of-effort categories, General Installation and Technical System Installation. General installation includes all common activities and preparations and associated logistics on the surface. Technical System Installation includes all efforts required for complete installation of the technical components underground and in the surface buildings where applicable (US/CERN site). General Installation is further broken down into logistics management, engineering support, equipment, vehicles, shipping-receiving, warehousing, and transportation. Technical System Installation covers the six machine areas, electron sources, positron source, damping ring, RTML, main linac and beam delivery. Each element of the WBS for both General and Technical System is then extended two levels further and populated with required labor as well as incidental material and equipment costs. Table 13.18 shows the top-level Installation WBS.

The installation estimates for the RDR is used as starting point for developing the TDR installation estimate. The scope of major changes impacting the installation work since RDR, are identified and defined sufficiently for scaling the RDR installation estimates. As an example of such scope difference, it was assumed for the magnets installation. A table of magnets count comparison between RDR and TDR was prepared. The major difference was identified to be in the damping ring area. Since the damping ring magnets are installed one above the others, specially designed vehicles are required for their transport. This is described in details under "13.7.5.3 Magnet underground transport and installation".**(Ed:** *insert label ref)*

Table 13.18: Top-Level WBS Installation

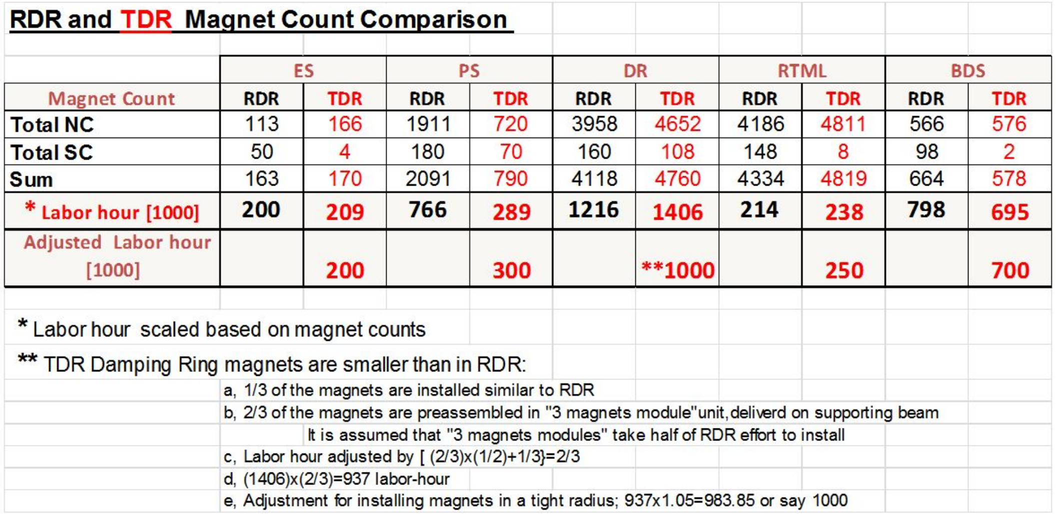
WBS					Component
1	7	3	1		General installation
				1	Logistics management
				2	Engineering support
				3	Equipment
				4	Vehicles
				5	Shipping-receiving
				6	Warehousing
				7	Surface transport
1	7	3	2		Technical system installation
				1	Electron source
				2	Positron source
				3	Damping Ring
				4	RTML
				5	Main Linac
				6	Beam Delivery

A meeting was held with the damping ring group leader and stakeholders to identify the details impacting the installation effort. Then, the installation labor effort scaled according to their installation complexity. This is further adjusted for the lesson-learned from the LHC installation and the recent similar projects. The result is shown in Table 13.19.

Since the main linac is a major cost driver, the installation of cryomodules and RF sources are modeled in details. This is described in the next section. For transport and installation of the cryomodules underground, specially designed vehicles are required. In order to avoid time-consuming load transfers between different items of equipment as well as transfer from the transport zone onto the support jacks. This is covered in details under "13.7.5.2 Cryomodule underground transport and installation".(**Ed:** *insert sec ref*)

Figure 13.44 shows the distribution of installation effort between General and Technical Systems and Fig. 13.45 indicates the relative labor effort for the various area systems for the Japan and the US/CERN sites.

Table 13.19: Labor hour estimate for the magnets installation (**Ed:** *Footnotes are too long, consider adding the information into text or removing it.)*



RDR and TDR Magnet Count Comparison

	ES		PS		DR		RTML		BDS	
Magnet Count	RDR	TDR	RDR	TDR	RDR	TDR	RDR	TDR	RDR	TDR
Total NC	113	166	1911	720	3958	4652	4186	4811	566	576
Total SC	50	4	180	70	160	108	148	8	98	2
Sum	163	170	2091	790	4118	4760	4334	4819	664	578
* Labor hour [1000]	200	209	766	289	1216	1406	214	238	798	695
Adjusted Labor hour [1000]		200		300		**1000		250		700

* Labor hour scaled based on magnet counts

** TDR Damping Ring magnets are smaller than in RDR:

a, 1/3 of the magnets are installed similar to RDR

b, 2/3 of the magnets are preassembled in "3 magnets module"unit, deliverd on supporting beam

It is assumed that "3 magnets modules" take half of RDR effort to install

c, Labor hour adjusted by [(2/3)x(1/2)+1/3}=2/3

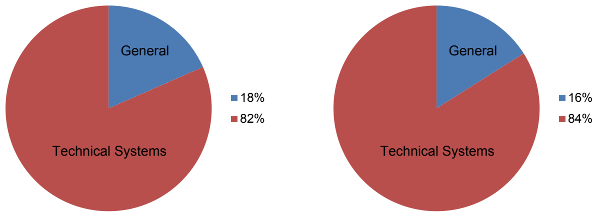
d, (1406)x(2/3)=937 labor-hour

e, Adjustment for installing magnets in a tight radius; 937x1.05=983.85 or say 1000

13.10.4 Model of Main Linac installation

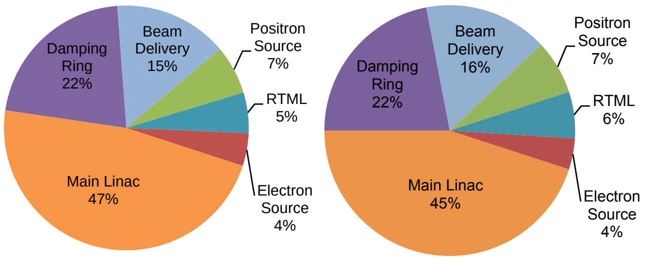
The Main Linac cryomodules and the RF sources represent a major installation effort, thus the RDR bottoms-up model for their installation is followed. The installation of a cryomodule unit is used as the criterion for all installed components for the RF unit in the Main Linac section. The assumption is based on installation of three cryomodules (one RF unit per day; Fig. ?? depicts the details.

Here the installation rate is three cryomodules (one RF unit) and associated services per day for each crew. Labor productivity is taken to be 75 %, or 6 hours per shift, given transport distances and handling difficulty. The model includes the number and size of the equipment, distances to installation, speed of transportation and estimates of number of staff and hours for each task. The installation of one the RF unit (three cryomodules) takes a total of 72 person-days as RDR installation study indicated. To estimate the installation effort to assemble an entire RF unit, the Japan site, using the DKS, considered as a model next. The Japan main Linac tunnel is similar to the RDR Main Linac RF assembly except that In that RDR one Klystron, one PDS unit, powers one Cyromodule unit (26 cavities) while in TDR it powers one and one half (1.5) cryomodules unit (39 cavities). The entire RF unit for the TDR includes Marx modulator (instead of Bouncer modulator in RDR), klystron,



(a) (b)

Figure 13.44: Distribution of effort between General and Area Systems for Japan and US/CERN sites



(a) (b)

Figure 13.45: Relative labor effort for the various area systems Japan and US/CERN sites

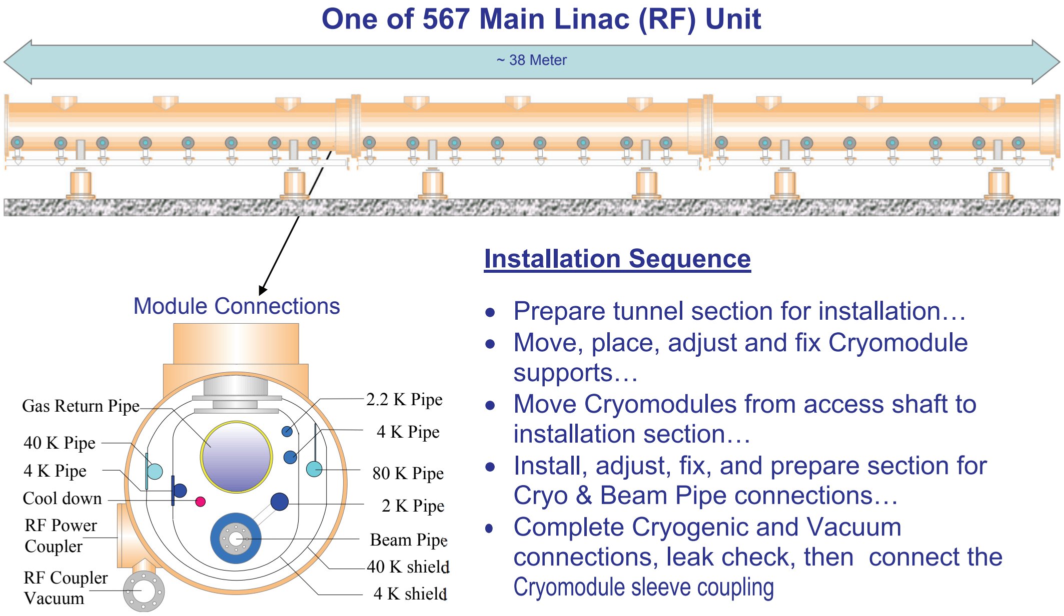
control racks, cable trays, control cables and complex waveguides. A section of the tunnels housing the components of entire RF unit are shown below,(**Ed:** *rephrase to eliminate 'below')* Figs. 13.47 and 13.48 are cross section and Fig. 13.49 is partial plan view.

The study indicated that the installation of the 3 cyromodules accounted for only about 25 % and 35 % of the effort to assemble an entire RF unit for Japan site and US/CERN site, respectively.

13.10.4.1 Installation planning in underground segment

Installation planning for the RDR was reviewed and modified for the TDR machine. It was further adjusted based on the lesson-learned from installation of the LHC and the most recent similar projects.

Here to create a cost effective, timely and safe installation plan, certain facility



One of 567 Main Linac (RF) Unit

Installation Sequence

- Prepare tunnel section for installation…
- Move, place, adjust and fix Cryomodule supports…
- Move Cryomodules from access shaft to installation section…
- Install, adjust, fix, and prepare section for Cryo & Beam Pipe connections…
- Complete Cryogenic and Vacuum connections, leak check, then connect the Cryomodule sleeve coupling

Figure 13.46: One of 567 Main Linac (RF) (**Ed:** *missing caption*)

conditions are assumed to exist prior to start of installation. Some examples include, but not limited to the availability of utilities, communication, above ground warehousing and equipment staging areas. Below ground, the personnel access rules, including safety and emergency considerations, must be defined and schedule of equipment and tunnel availability must be known. Once these and details of the technical components are known, a very general model, both in time and 3-D, can be developed as shown schematically for the main linac (see Fig. 13.50).

Here the 72 man crew is working in a (moving) one km section of the tunnels at the three cryomdules per day rate, showing the different activities which spread over a six week time span. Two crews are working independently starting at shafts 7 and 11 and work towards shaft 9. Similar activities and crews will be working in other sections of the linac tunnels where applicable (i.e., in Japan site) when become available. This is also true for the centeral complex of injectors and damping ring.

The TDR estimate assumes a 3 year installation schedule, a six month period of ramp-up and on the job training, and 75 % efficiency. In tunnel activity are concentrated on a day shift, with transport and staging on swing shift. Based on this multishift model, the total manpower to fit all the installation activities into the

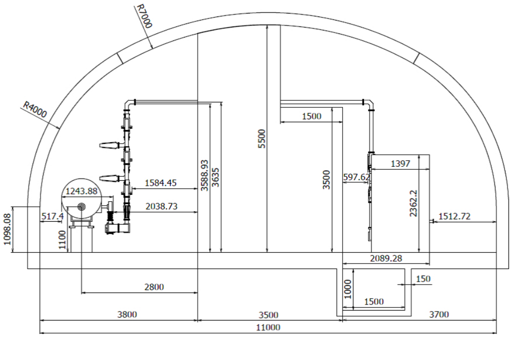
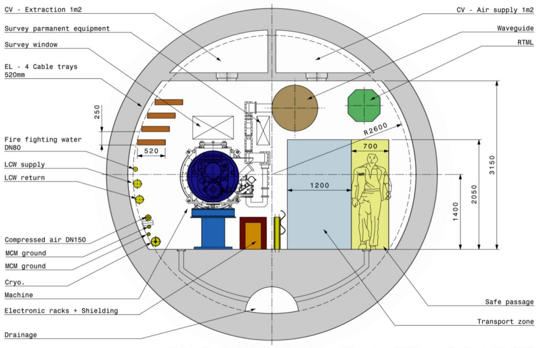


Figure 13.47: Cross section of ML tunnel-Japan site



ILC - Typical Cross Section - Diameter 5200mm - Scale 1:25 (A3)

Figure 13.48: Cross section of ML tunnel-CERN site

3 year peak period, are about 450 people on day shift and another 250 on swing shift in various part of the tunnel. There are also about 100 people involved in surface logistics.

In the absence of a detailed fabrication plan for the major machine components, a very top level installation schedule was developed to integrate with construction schedule. This is covered under section 13.9 “Construction schedule”.**(Ed:** *insert sec ref)*

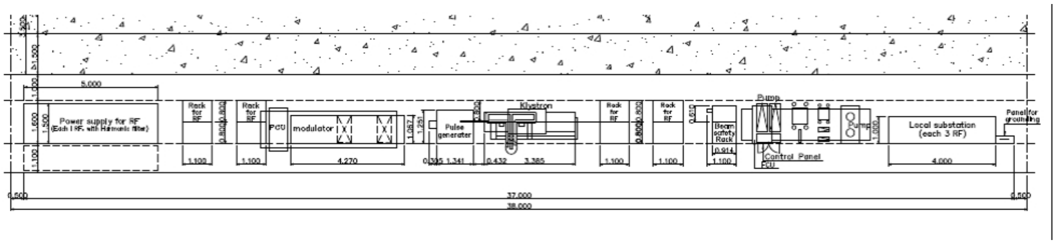


Figure 13.49: Partial plan view of ML tunnel service section for Japan site

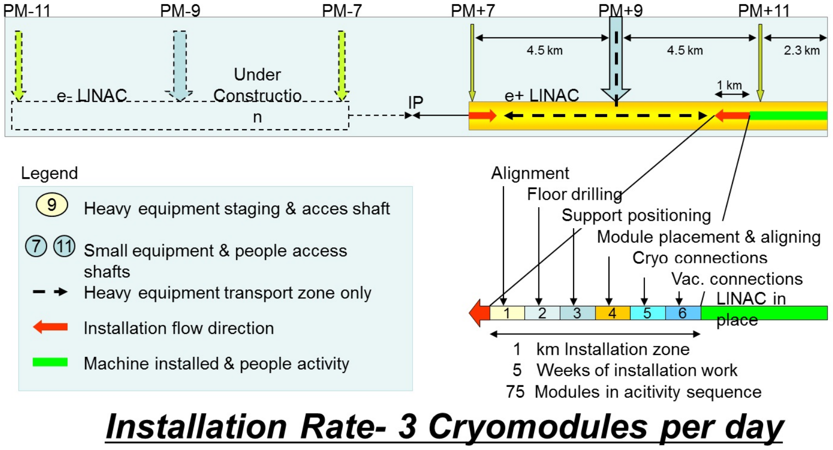


Figure 13.50: Installation Model for main linac components in underground segment

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