CHAPTER 5

Conventional Facilities

Contents

5.1 Introduction

This section discusses the issues associated with the conventional facilities required for GLC. The major parts of the conventional facilities for GLC include long tunnels to accommodate the linear accelerators (linacs) and the experiment halls where the detectors are to be installed. Fig. 5.1 shows a bird's-eye view of the GLC site in its vicinity of the experiment halls and the campus. In addition, the linear-collider system demands special considerations on numerous utility facilities, such as: the power supplies, cooling, air conditioning, draining, accident prevention, safety and fire fighting. Their system designs, together with the construction sequence and scheduling, are also discussed. The studies and design have been conducted with close cooperation with companies in various fields, such as civil engineering, facility design, electric-power and cooling systems.

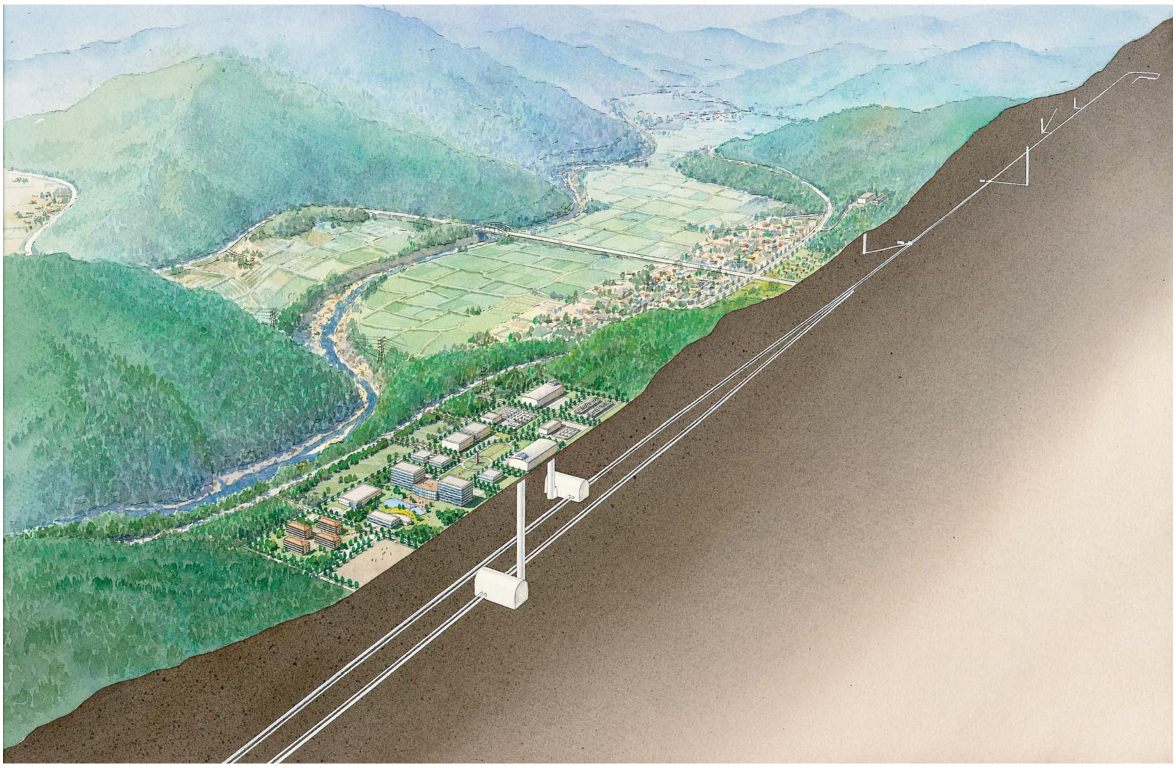

Figure 5.1: *Bird's-eye view of the GLC site. The laboratory campus on the surface is shown. Underground experiment halls and part of the accelerator tunnels are also shown.*

GLC will be operated at an initial center-of-mass energy of up to 500 GeV. However, since the upgrade program up to, or beyond, 1 TeV is part of the project plan, the critical elements of the conventional facilities need to be able to cope with the possible highest beam energy without major re-engineering. Consequently, it is assumed that the main tunnels will have a total length of ~30 km. Likewise, the present baseline plan assumes that the entire set of facility equipment for supporting 1 TeV operation, such as AC power distribution, cooling water and air conditioning, be installed during the initial stage construction.[1] Since the number of active RF and magnetic elements will depend on the collision energy, the actual number of active cooling towers and power substations will vary, depending on the collision energy.

The detailed structure and the construction methods of the accelerator tunnels and the experiment halls are subject to changes, depending on site where the facility is built. Especially, a general feature of the underground composition, such as soil or bedrock, affects the optimal design of the facility. However, the designs of most of the auxiliary systems and the infrastructures presented here should be applicable to any site location. General features of the site candidates are found in Chapter 6.

As discussed in Chapters 4 and 6, a number of criteria have been devised for the construction site of GLC. One of the important issues is the stability of the ground, since many elements of the GLC accelerator system require unprecedented accuracy and stability of their alignment, compared to accelerators in the past. For the studies of conventional facilities presented in this Chapter, the GLC construction site is assumed to be in an area with a bedrock, which is considered to be most advantageous from the viewpoint of ground motion.

5.2 Site Layout

5.2.1 Underground Tunnels

Fig. 5.2 shows a schematic diagram of the underground tunnels. The tunnels are subdivided into the following five sections:

	System	Area	Length
1.	Electron injector system	from electron gun to bunch compressor 2	1.7 km
2.	Electron main linac	(including the diagnostics section and bypass)	14.1 km
3.	Final focus section	(including the experiment halls)	1.9 km ×2
4.	Positron main linac	(including the diagnostics section and bypass)	14.1 km
5.	Positron injector system	including the electron linac, positron production target, up to bunch compressor 2	2.3 km

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[1] On the other hand, as for beamline components such as, RF power sources, accelerator structures, waveguides, focusing magnets and beam monitors for the main linacs, only approximately half of them will be installed for supporting initial operation at $E_{CM} = 500$ GeV.

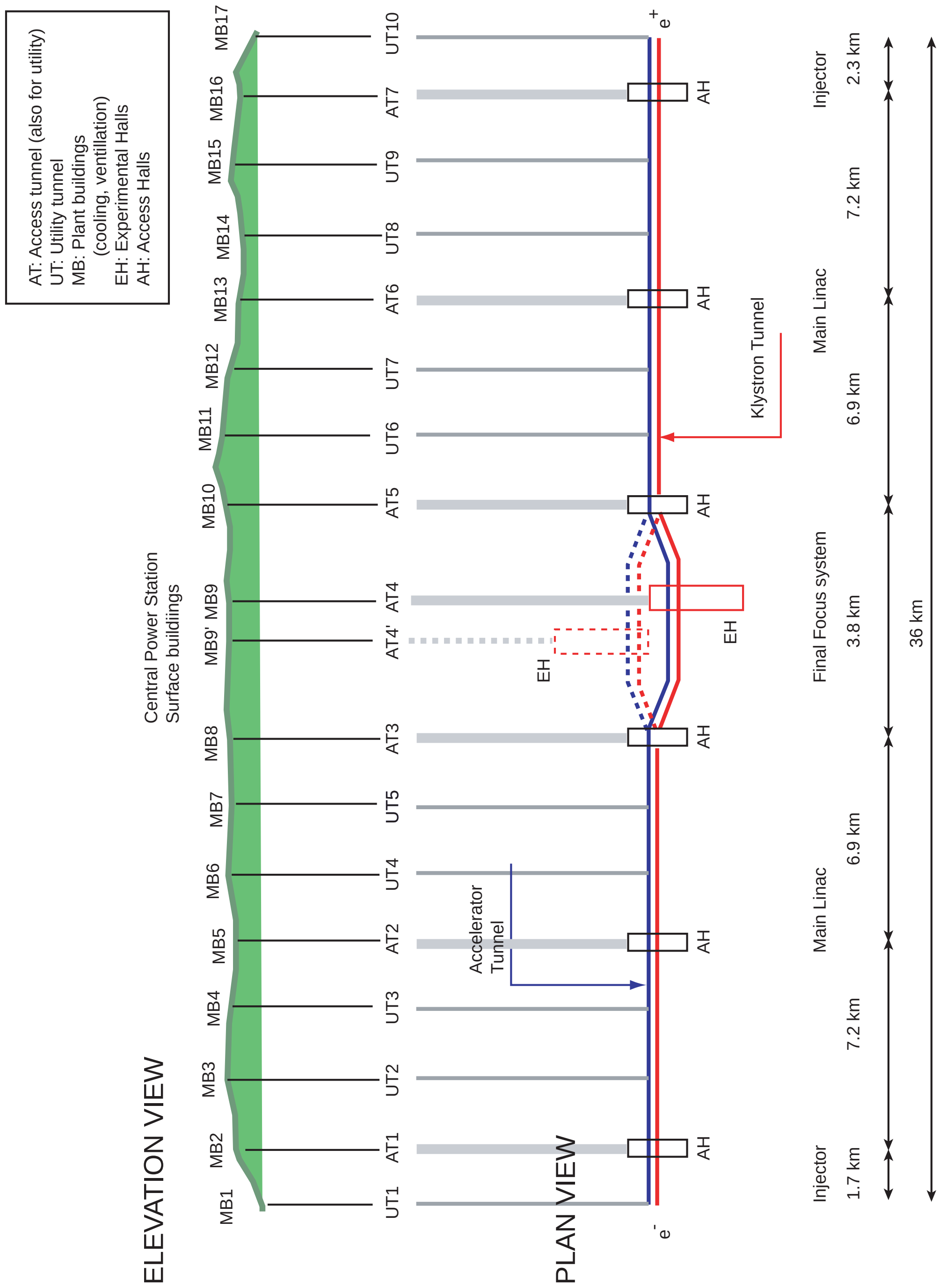

Figure 5.2: *Schematic view of the underground tunnels.*

The present baseline design of GLC has a single section for electron-positron collisions, with provision for two collision points for running two experiments alternatively as an option. In this optional scheme, two experiment halls will be provided and the tunnels for the final focus section will accommodate two sets of beamlines for each of the electron and positron parts.

The total length of the beamline in the underground sections amounts to $\sim$ 36 km. Among the sections, injector systems for electron and positron beams are installed in tunnels with complex structures at either ends of the site, as described in Chapter 4. Other sections are housed in almost straight tunnels running between both ends of the site. All systems will be constructed so as to fit in about a 33 km long site area.

While the subterranean depth changes considerably depending on the site, it is generally assumed to be several tens to 200 m between the underground and surface facilities. As described later, most of the underground sections will have two tunnels running in parallel. One of them will be used for power suppliers, such as the modulators, klystrons and data processing or control electronics elements, and the other for the accelerator structures, focusing magnets and beam instrumentation. This design is the best suited to achieve continuous maintenance of the machine during the running time with sufficient human access for active devices, which will lead to a high integrated luminosity of the beam collision.

As shown in Fig. 5.2, the accelerator tunnels are intersected by auxiliary tunnels (either mining shafts, inclined shafts or level pits) every $\sim$ 2 km, which are connected to the ground surface. They are used for tunnel access by personnel, as well as routing the cooling water, power and control signal cables. About one third of the auxiliary tunnels are to be used to introduce the boring machines during tunnel construction, and for the delivery of materials and equipment during installation; these are called “Access Tunnels” (AT). The experiment hall is associated with a special access tunnel which will be used as a path for installing the detector facility. The remainder of the auxiliary tunnels are called “Utility Tunnels” (UT) hereafter. Fig. 5.2 shows that the GLC site plan has ten UTs (UT1–10) and seven ATs (AT1–7), including one for the experiment hall (AT4). When the second colliding section is approved to be constructed, there will be one more AT (AT4’) to access an additional experiment hall.

5.2.2 Surface Facilities

Facilities on the ground surface include: a central power station, research laboratory buildings, buildings for air conditioning apparatus, cooling towers, and others. The central power station and research buildings will be built on the central campus, located near the center of the linear accelerator. Cooling stations will be installed at every $\sim$2 km, corresponding to the access areas for the ATs and UTs.

Provisions must be made to accommodate a large number of visiting scientists and engineers from around the world. A transportation terminal, guest houses, and other service facilities for these people and their family members, have to be prepared.

An outline of the facilities on the ground considered here is given in Table 5.1. The facilities for researchers will be gradually expanded during the long-term activities of the project. Here, we list the current plan for the initial form of the laboratory. The land for the central campus is assumed to be 250,000 m^2 in the current design.

Facility	Contents	Floor space (m^2)	Number
Main Power Station	Special high voltage power station	800	1
Outside field		5600	1
Equipments building	Air conditioning for tunnel	1000	17
Outside field		250	17
Cooling Facility	Cooling towers	1500	17
Access Hall	Access entrance into the tunnel	200	7
Assembly Hall	fabrication of accelerator/detector	8000	1
Research Building	Researchers' office, Conference hall, Administration, Bureaucratic office, Security center, Radiation protection, Computing	10000 ($\sim$1300 $m^2 \times$7F)	1
Hostel	Hostels	2500	2

Table 5.1: *Summary of the on-site facilities on the ground.*

5.3 Tunnel Layout

This section describes the composition and scale of the underground facilities (tunnels and halls) for GLC.

5.3.1 Main Tunnels

The tunnels for the injector systems, main linacs, and final focus system consist of two parallel tunnels (Main Tunnels). All of these sections have the same double-tunnel structure, while the boring method would be different section by section, as described in a later section (see Sec.5.3.8). Fig. 5.3 shows a conceptual view of the double-tunnel structure. The details of the components that are installed in each of these tunnels are discussed in Chapter 4.

One tunnel has an inner diameter of 3 m for the accelerator structures, vacuum systems, focusing magnets and beam instrumentation, and is called the "Accelerator Tunnel". The other tunnel, with an inner diameter of 4.5 m, is for RF power sources (klystrons and modulators) and other power sources for the magnets as well as data-processing electronics circuitry for beam instrumentation, and is called the "Klystron Tunnel." The use of these two, parallel tunnels for the main linacs stems from

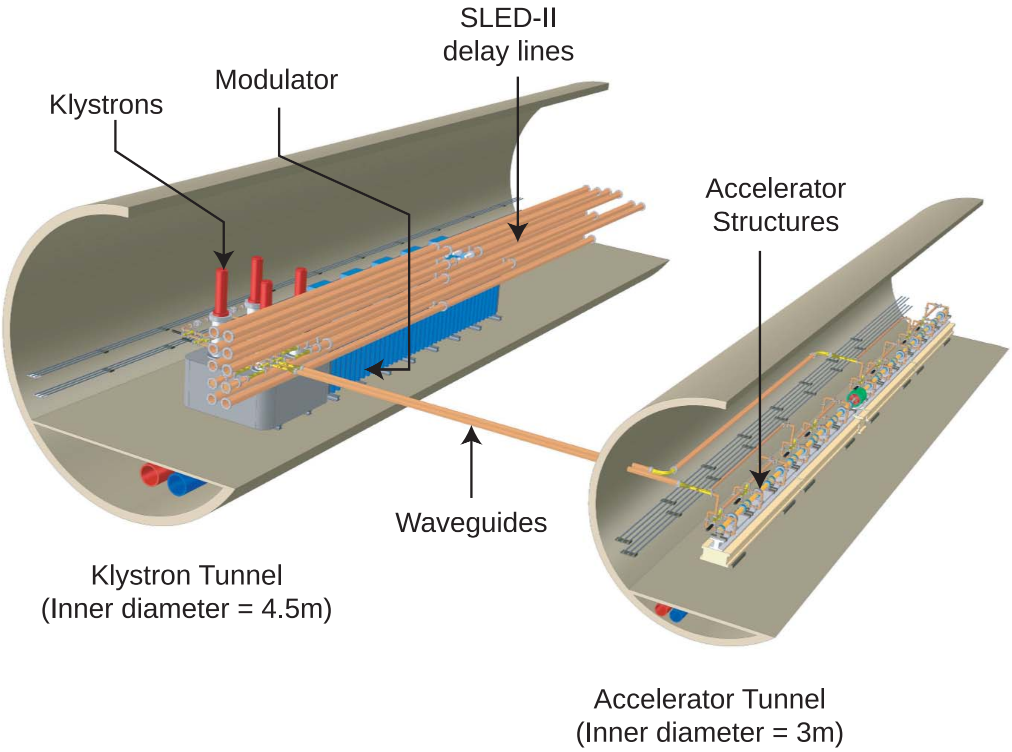

Figure 5.3: *Image view of the components installed in the double-tunnel structure of the Main Tunnels. The Klystron Tunnel (left) houses high-power klystrons and modulators together with power supplies for the magnets and data-processing electronics circuitry for the beam instrumentation. The Accelerator Tunnel (right) houses the accelerator structures installed on support girders, which receive RF power from the klystrons. The beam is accelerated in the Accelerator tunnel, while part of the Klystron Tunnel may be occupied by support personnel and scientists for repair, diagnosis and upgrades.*

the requirement to allow servicing some of the power source components in the Klystron Tunnel while continuing operation of GLC with accelerator elements that are driven by the remainder of the RF power sources.

The wall-to-wall separation between the two parallel tunnels is designed to be 5 m (corresponding about 8.8 m between the centers of the two tunnels). The optimal separation was chosen based on several considerations. The most important ones are:

1. The bedrock surrounding the tunnels should be able to maintain sufficient strength. If good bedrock is assumed where major reinforcement work on the tunnel is considered not to be necessary, the minimum required tunnel separation is roughly 4–5 m.
2. The soil between the two tunnels needs to partially serve as a radiation-shield material. This is because the Klystron Tunnel is expected to be, at least momentarily, occupied by service

personnel, while beam operation is taking place in the Accelerator Tunnel. A separation of about 2 m is sufficient for this purpose.

Smaller tunnels with an inner diameter of 30 cm will be prepared at every ~13 m, connecting the Klystron and Accelerator Tunnels. They are used to route the RF power, electric power, signal cables and cooling water.

5.3.2 Access Tunnels

An Access Tunnel (AT) connects the ground surface to the Main Tunnels or the experiment hall. It serves as a passage for the people, cooling water, electric power lines, and status and control signal cables for the accelerator. During construction of the facility, the ATs will be used to carry in and out boring machines, such as TBM (Tunnel Boring Machine), and to remove rocks and soils produced in the boring (muck). Seven access tunnels (AT1–7 in Fig. 5.2) will be built along the underground facility.

The length, size and structure of the ATs must be optimized according to the site geometry and access roads. An AT could be a level pit, an inclined shaft, a mining shaft, or a combination of those, depending on the ground conditions and road traffic access conditions of the site. In the case of a level pit or inclined shaft, the inner diameter of the AT would be 6 m. The typical length of the AT with this scheme is about 500 m, while the length considerably changes point by point and depending on the site location. The diameter for the AT to an experiment hall is designed to be 15 m, because large detector facility elements need to be brought in through this AT. Also, if an AT is built as a mining shaft (vertical shaft), its inner radius is required to be larger than 15 m so that a TBM equipment can be lowered through it.

5.3.3 Utility Tunnels

Utility tunnels (UTs) also connect the ground surface and the Main Tunnels. However, when GLC is completed, they will be used primarily for routing the cooling water and the power cables. During the construction period, they will also be used for removing the muck that is produced in the boring process. The inner diameter of a UT will be about 4 m, suitable for maintenance and servicing.[2] There will be ten UTs (UT1–10 in Fig. 5.2).

5.3.4 Experiment Hall

An experiment hall is to be prepared at the collision point of the electron and positron beams. The size of the hall in the present design is 85 m× 40 m and 40 m high, sufficiently large for installing a large-scale detector and electronics huts with adequate space for the final assembly of the detector

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[2] Some of the UTs might be enlarged so to have a smooth human access to the underground facilities.

and its maintenance. At least two cranes are to be provided, one with a 200 t capacity and the other 10 t. Fig 5.4 shows a conceptual design for the hall.

The stability in the ground at the collision point is of crucial importance for high-luminosity operation of the linear collider, as described in Chapter 4. The optimal design of the structure of the hall and the planning of its civil engineering require a careful simulation of the floor motions. The choice of the materials and the thickness of the floor need to be optimized accordingly. This work is in progress.

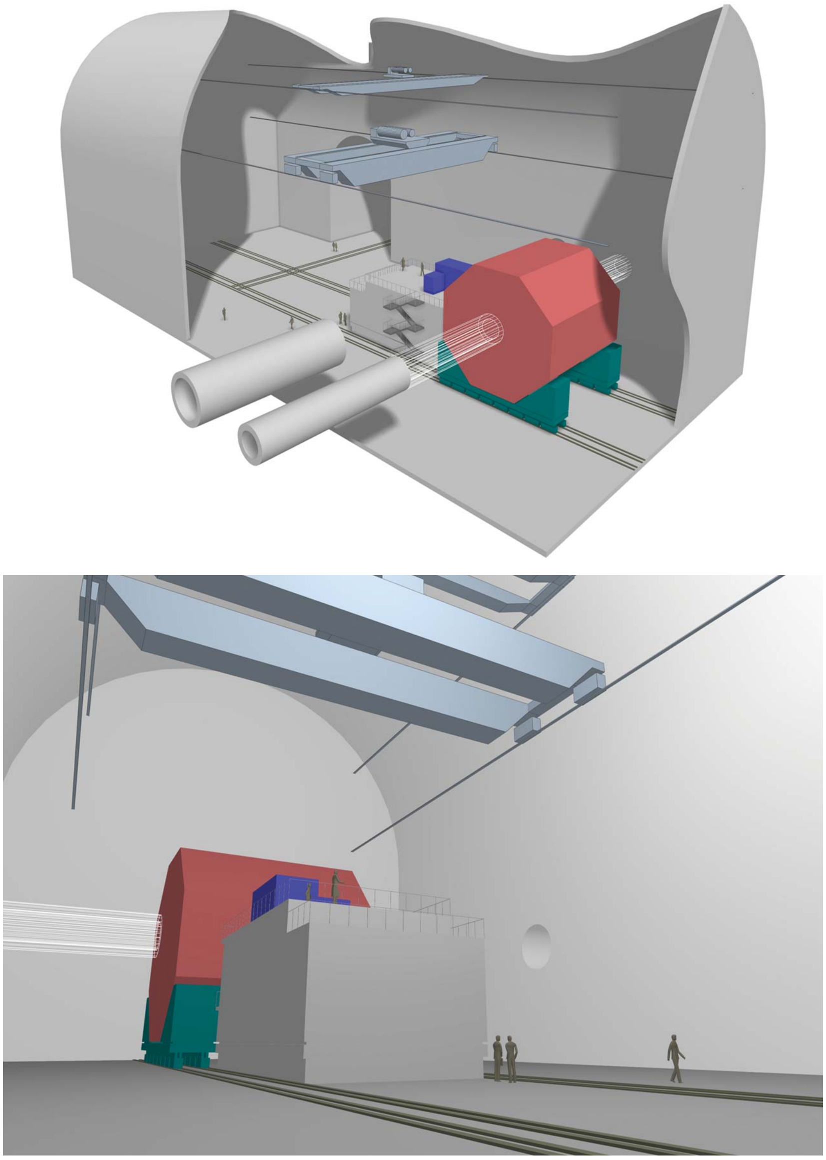

Figure 5.4: *Image views of the experiment hall.*

5.3.5 Substations

At some of the knot points of the Access and Utility Tunnels and the Main Tunnels (corresponding to AT1–3, AT5–7, UT2–9 in Fig. 5.2), a hall (substation) for underground utilities will be built. Hence, there will be 14 substations to be prepared in the underground area. Each substation has a 66 kV transformer to receive electric power from the central power station on the surface, a heat exchanger for cooling water, and a drainage storage tank, which are described in the following subsections. The size of the substation is assumed to be about 500 $\mathrm{m}^2 \times 6$ m high.

5.3.6 Access Hall

In addition to the substations mentioned above, an Access Hall (AH) will be built at each intersection of an Access Tunnel (AT1–3 and AT5–7 in Fig. 5.2) and the Main Tunnel, in order to be an underground access-control area, a temporary storage area, and so on. A circular dome with a diameter of $20 \sim 25$ m is currently being considered, as shown in Fig.5.5. The details of this structure can vary, depending on the type of AT, *i.e.* whether it is a vertical shaft of a level pit. Within each of the AHs, the main accelerator will be contained in a concrete shield wall.

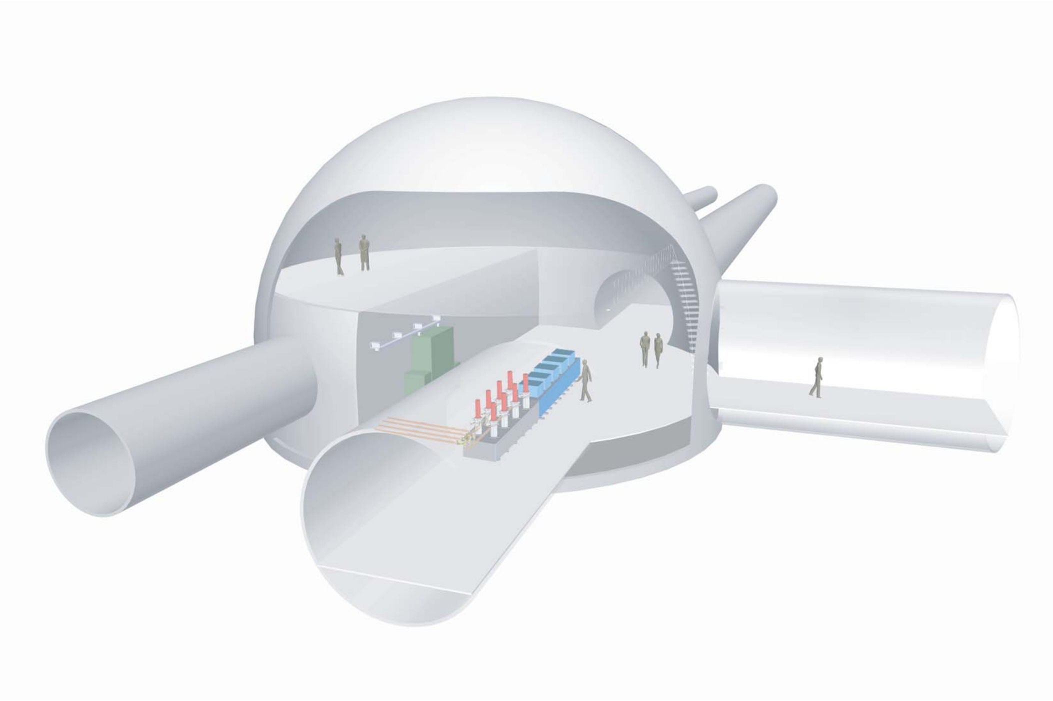

Figure 5.5: *Image view of an access hall.*

5.3.7 Beam Dump Halls

Two underground caves will be prepared in order to accommodate the beam dumps (see Chapter 4). These beam-dump halls will be located $\sim$ 200 m downstream past the collision point for the outgoing electron and positron beams. The size of each beam dump hall will be about 1500 m^2 (60 m long) and 15 m height. The size was optimized to cope with the high power of the intense beam to be dumped with a sufficient radiation shield during the high-luminosity operation of the collider. The beam is to be transported for $\sim$200 m from the collision point to the beam dump through a single tunnel with 3m diameter.

In addition to these halls, there will be a few small beam dump areas to be prepared for machine protection, as described in Chapter 4, at some of the diagnostic sections of the accelerator. A design optimization is underway.

5.3.8 Tunnel Boring Method

In the case that the construction site is a region with rock bed, the boring method for each tunnel is supposed to be as follows:

- **Tunnels for main linac:**
  Both the Accelerator Tunnel and the Klystron Tunnel are sub-divided into four sections along the full length. At each end-point, an access hall is prepared for mounting and dismounting the Tunnel Boring Machine (TBM). The four sections are bored simultaneously while supplying two TBM for each section, one for the Accelerator Tunnel and one for the Klystron Tunnel. Hence, eight TBM machines will be used. The boring of the connection tunnel between the Accelerator Tunnel and the Klystron Tunnel, which is necessary for wave guides, will start when about one third of the Accelerator and Klystron Tunnel is bored. Since the boring work for wave guides interferes with the space for the system to transport earth away, the route for transporting the earth away will be changed while utilizing access and utility tunnels in sequence.

- **Tunnel for final focus system:**
  The TBM method is supposed to be used. The tunnel is to be bored with one TBM for the Accelerator Tunnel and another TBM for the Klystron Tunnel, in a manner similar to that for the tunnels for the main linacs.

- **Tunnel for pre-accelerators:**
  While the double-tunnel structure is the same as that for the main linacs and the final focus system, boring with TBM is expected not to be optimal for the pre-accelerator sections, such as a damping ring, because of the curvature of the tunnel. The New Austrian Tunneling method (NATM) is assumed to be used.

- **Experiment hall:**
  NATM is assumed to be used. A large area underground hall is usually constructed in two

steps, namely, work for the roof region and the floor region. First, boring of the roof region is carried out, then expanding downwards with a few meters steps. Geological strength of the underground area is desired to be good enough in order to excavate such a large experiment hall. Otherwise, special treatments must be made to hold the structure, which will increase the construction cost. In a worse case, the excavation will require new technologies. The rough upper bound on the hall span is shown in Fig. 5.6 along with past achievements as a function of the unconfined compression strength according to the present technology. To construct a detector hall with about a 40 m hall span, more than 600 kgf/cm^2 of unconfined compression strength is necessary with a present technology. In the case that there exists a weaker region than the limit of 600 kgf/cm^2, if the region is localized, it could be coped with by applying an additional supporting system.

- **Utility Tunnels and Access Tunnel:**
  NATM is assumed to be used for a level pit or an inclined shaft. In the case that a vertical shaft is necessary, firstly excavation will be carried out up to about 20 m below ground level for the earth-retaining support using liner-plate bracing, and then boring below 20 m will be done by NATM.

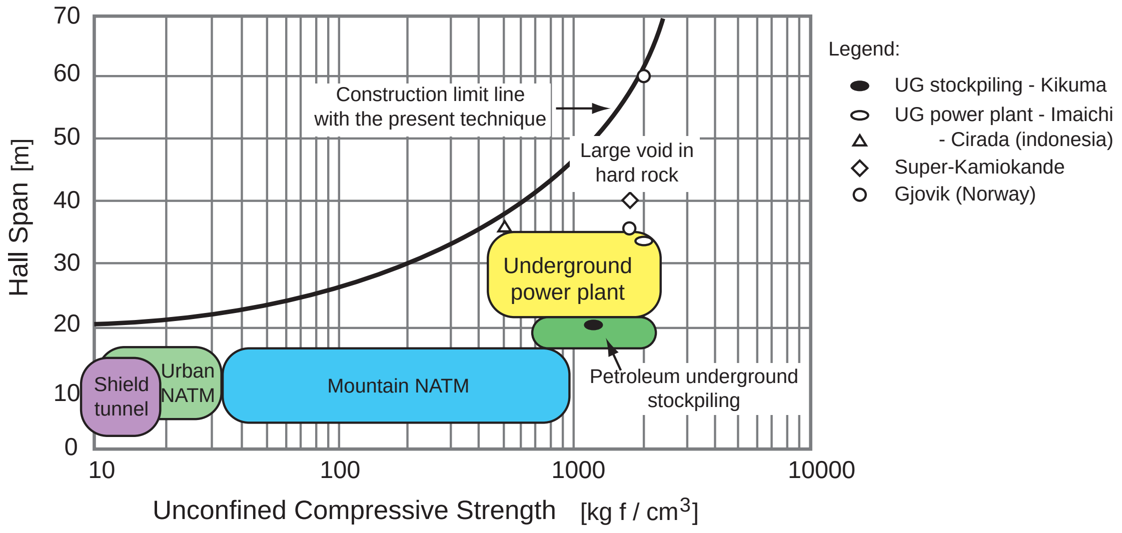

Figure 5.6: *Unconfined compression strength of typical large-scale underground tunnels and caves.*

5.4 AC Power Distribution

5.4.1 System Overview

This section discusses the infrastructures for electric power necessary to operate the GLC facility. Fig. 5.7 shows the configuration of the power-distribution system. The electric power delivered from an electricity company will first be received by a central power extra-high voltage substation (central power station). The service voltage is assumed to be 275 kV, which is in wide use in Japan. At the central power station, the received power will be converted to a lower voltage of 66 kV. It will then be redistributed to over ten local extra-high voltage substations (substations) (see Sec.5.3.5) along the Main Tunnel. Each substation is to be equipped with a 66 kV transformer, which further reduces the voltage to 6.6 kV. The 6.6 kV AC power is distributed through triplex cables to thousands of small converters which finally drive the accelerator system, cooling and other utilities inside the tunnels. In addition, the power for the facilities on the ground at each access point, such as the cooling tower, will be supplied through 6.6 kV lines from the 66 kV system.

The central power station (275 kV) and the 66 kV substations will be monitored and controlled at a central control room. Lower voltage lines after the 66 kV transformers will be controlled locally. Emergency systems must be prepared according to the legal regulations. A ground earthing system also needs to be provided.

5.4.2 Components within the AC Distribution System

Brief descriptions are given for the components that constitute the AC distribution system at GLC, or for the elements that have close links to it.

- **Central Extra-high Voltage Substation:**
  A central extra-high voltage substation (central power station) will be built on the ground surface, close to the collision point. Here, the supplied voltage (275 kV) is lowered to 66 kV and redistributed to the local extra-high voltage substations. The main circuit of the power receiving equipment will be double-ended. The two systems are switched automatically in the case of operational anomalies. The facility is the close tight type (GIS) for outdoors. The maximum allowed power consumption is set to 350 MVA. Table 5.2 gives the detail. The transformer is an oil-immersed type for 275 kV.
- **66 kV Local Extra-high Voltage Substation:**
  In total, 14 sub-converters will be used. Each of these will be located at each substations in the underground area (see Sec.5.3.5). The higher harmonics and reactive power originating from the downstream systems are compensated in the system. The maximum power allowed is set to

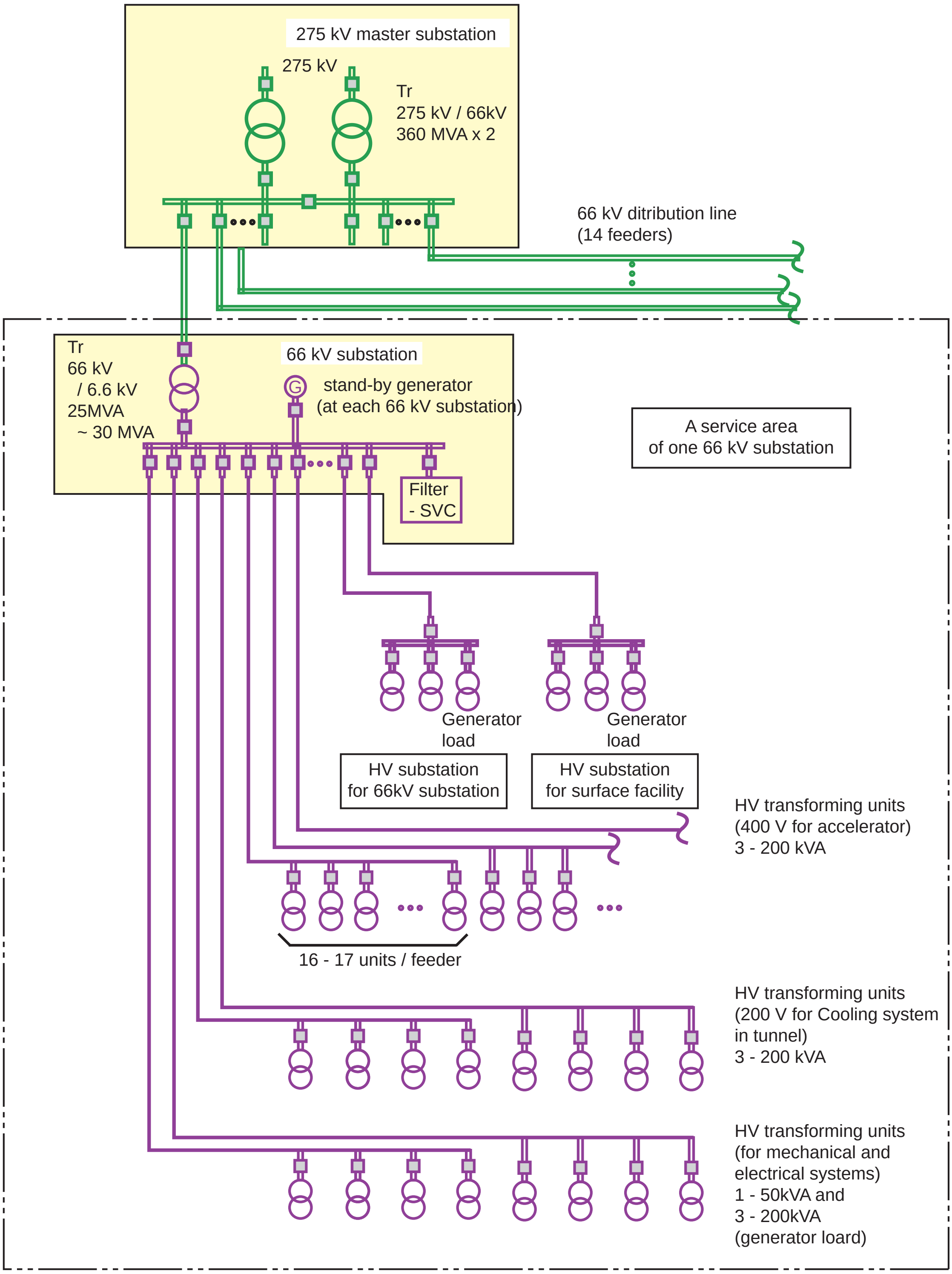

Figure 5.7: *Schematic drawing of electric power distribution system.*

Items	Maximum Allowed Power Consumption	Comments
Main Accelerator	300 MW	
Cooling Tower	17 MW	1 MW/unit×17 (surface)
Lights and cooling in tunnel	4 MVA	100 VA/m×36 km
Air conditioning system	9 MW	0.5 MW/place×17 (surface)
Sub-total	330 MW	
Other facilities	20 MW	Central power station, control, computing
Grand total	350 MW	

Table 5.2: *Maximum power acceptance assumed for operation at* $E_{CM} = 1$ *TeV.*

25–35 MVA for each 66 kV substation. The secondary voltage is 6.6 kV. Static capacitors are used in the 6 kV main bus-bar to stabilize the subsequent 6.6 kV systems.

- **6.6 kV Transforming System:**
  This system will supply the driving power for the RF power sources (400 V), accelerator cooling system (200 V) and other utilities inside the tunnel (200 V single phase). In the current design, the transformers are located under the floor inside the Klystron Tunnel. A simple and small system is used to reduce the space requirement inside the tunnel.

- **Main Power Distribution Cables:**
  Twisted cables (Triplex) are used to distribute 66 kV and 6.6 kV in the tunnel. The cabling is made in the Klystron Tunnel.

- **Lighting:**
  The design illuminance of the main facilities is 200 lux for inside the tunnels and 500 lux for the control rooms. In the Accelerator Tunnel, exchangeable parts and materials with less radiation damage are used to cope with radiation safety. In the Klystron Tunnel, there are no such limitations.

- **Backup Powers for Emergency:**
  A standby generator of 6.6 kV will be prepared at each 66 kV substation. The standby generators are used for water pumps and smoke evacuation as required by the laws. A DC power supply system will be prepared for controlling the substations and the emergency lighting system. The distribution of the power takes into account the limitation of the DC line length. A non-interruptible power supply (UPS) will be equipped for the main control system of the power distribution system.

5.5 Cooling Water and Air Conditioning

5.5.1 Cooling Water System

Fig. 5.8 shows an outline of the cooling water system and the concept for the divergent cooling unit. A major part of the heat generated in the accelerator complex will be disposed of by a cooling system. The elements within the cooling system include: cooling towers on the ground to cool the primary cooling water, pipes to deliver the water inside the tunnel, heat exchangers between the primary and secondary water, and a fine temperature-control system for the secondary water which is to be installed at each accelerator element.

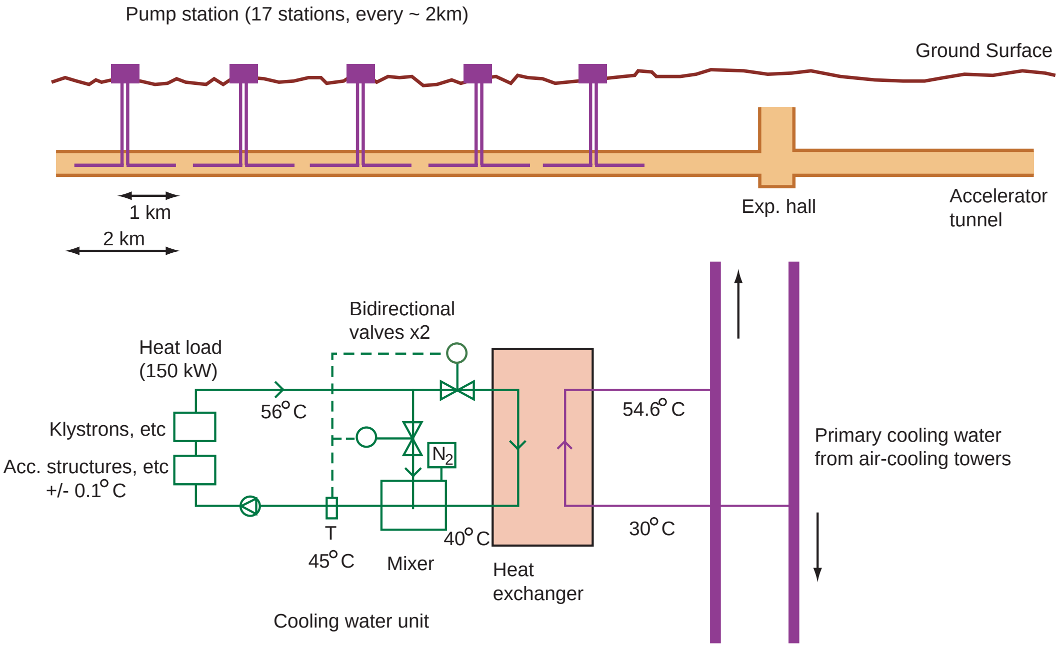

Figure 5.8: *Schematic diagram of the cooling system.*

Hermetic air-cooling towers, located at every ∼2 km on the ground, will provide the accelerator with primary cooling water at 30°C (outside atmospheric temperature at 25°). The GLC will have 17 towers, each with a cooling capacity of 30 MW.

The temperature tolerance of the supplied primary cooling water is set to be about ±2°C. The water temperature returned from the accelerator is about 55°C. Inside the underground tunnels, the water line is piped with the reverse-supply scheme, and branched at every 7 m to provide cooling water to each heat exchanger.

The required fine temperature control and purification of the secondary cooling water will be made by control units dedicated to each device category. Therefore, the quality of the primary water supplied into the tunnels may be at the same level as city water, and steel tubes can be used for piping. Since the altitude difference between the ground where the cooling towers are located and the tunnels may reach 200 m at maximum, all pipes, valves and shrinkable connectors and other components are required to withstand up to 300 kPa of pressure. In the current design, the expansion of the pipes due to temperature changes, especially at the beginning of operation after a shutdown, is absorbed by a set of connection pipes designed for that purpose.

5.5.2 Air-Conditioning System

While most of the heat generated in the operation of the accelerator is removed by the cooling-water system installed in the accelerator devices, a few percent of the generated heat will spread in the air passing through heat insulators. A ventilation and air-conditioning system is required to provide the personnel and equipment underground with clean air and a suitable air temperature. Fig. 5.9 shows the concept for tunnel ventilation and the air-conditioning system.

The ventilation and air-conditioning system are designed with the following operational conditions in mind:

- Accelerator Tunnel: circulation rate of $\sim$ 0.2 times/hour, and low heat generation in the air (negligible), 30°C max (tolerance not determined).
- Klystron Tunnel: circulation rate of $\sim$ 0.2 times/hour. Heat generation of $\sim$ 200 W/m, 30°C max (tolerance not determined).

The outside air is processed with an air-handling unit on the ground surface. The Accelerator and Klystron Tunnels share the same outside air-handling units. An air inlet for the Accelerator and Klystron Tunnels is located every $\sim$4 km. A Utility Tunnel between the two will serve as an air outlet. In total, there will be 9 inlet and 8 outlet air-handling units. Each inlet air-handling unit is equipped with an air-cooling heat pump chiller. It cools down the outside air in the summer and warms up the air in the winter without humidification. This will provide a sufficient air-conditioning capability inside the Accelerator Tunnel, because heat generation into the air is relatively low there.

As for the Klystron Tunnel, however, the heat generation is relatively high, and there will be frequent human access for maintenance of active accelerator elements. Therefore, fan coil units are used for the air cooling in the Klystron Tunnel, as shown in Fig. 5.9. Cold water for the air conditioning is produced at the cooling stations (equipped with air-source chilling units) located on the ground surface every $\sim$2 km, where cooling towers for the primary cooling water also exist.

At each station, the cooling water for the fan coil units is delivered to the underground facilities through the Utility and Access Tunnels, as is done for the primary water for the cooling-water system, and processed with a heat exchanger. It is then provided to each fan coil unit located every $\sim$10 m, and then returned using the reverse return method.

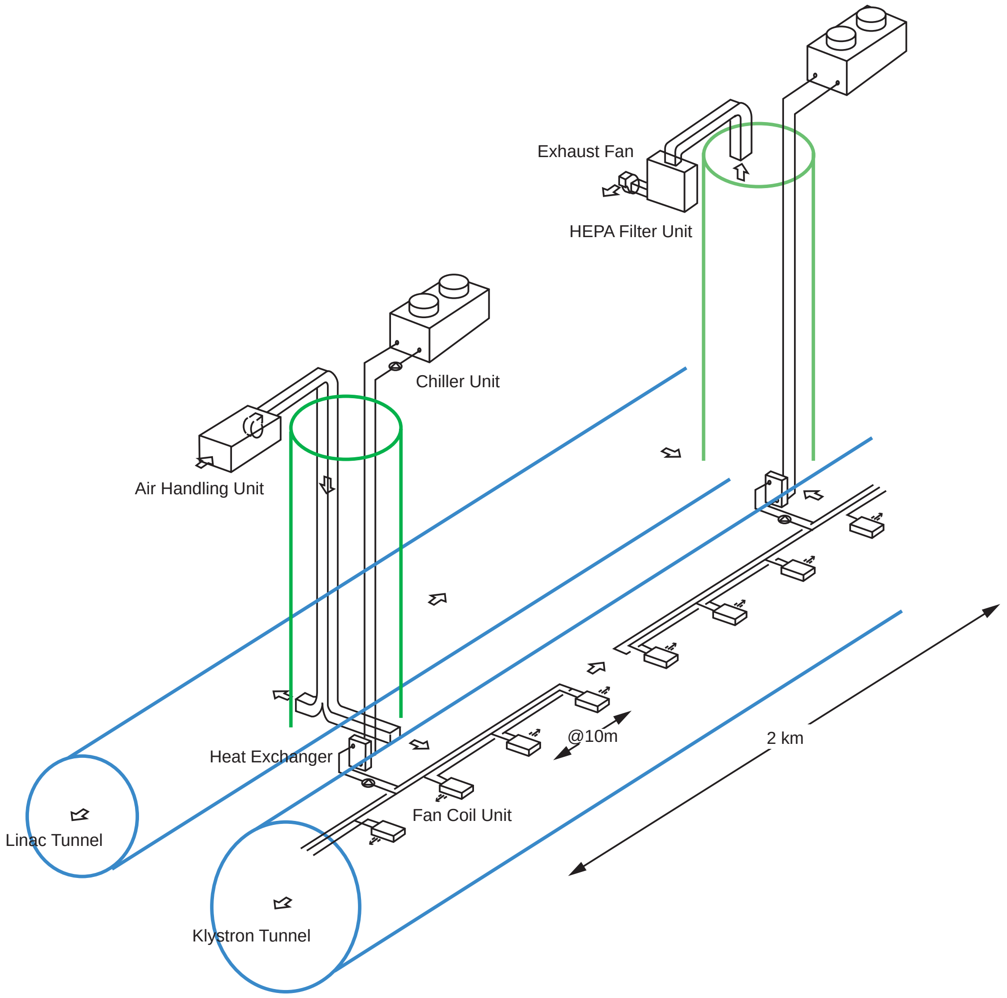

Figure 5.9: *Schematic diagram of the ventilation system.*

5.5.3 Draining System

Drainage from the fan coil units for the air conditioning, spring water inside the tunnels and leaked cooling water is collected into a spring-water storage, located every $\sim$200 m within each tunnel. Collected water is pumped to storage tanks, which have a volume of $\sim$ 10 m^3, located at each of the substations, and further pumped up to station on the ground surface. Fig. 5.10 shows the concept for the tunnel draining system.

In addition, water supply and pump stations are necessary on the ground surface.

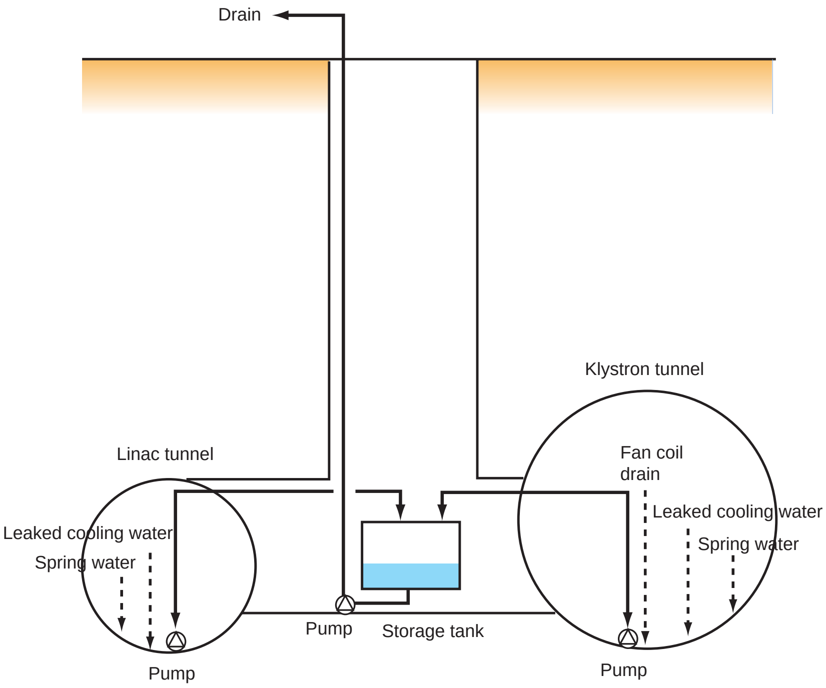

Figure 5.10: *Schematic diagram of the drainage system.*

5.6 Information Network and Safety Systems

The following items will be prepared for the information network system:

- PHS inside the laboratory and all facilities related to it
- Broadcasting facility
- Checking cameras (one per 50 m inside tunnel)
- LAN cables
- TV cables

These are required to monitor the status of the hardware within the tunnels during operation, as well as to support the communication between the personnel inside the tunnels and the control center during a hardware installation and maintenance period.

Safety systems at GLC must be prepared according to national laws concerning buildings (basic building law) and fire defense. The Main, Access and Utility Tunnels are categorized as “cave roads”, and are not subject to the regulations for buildings nor fire defense (some negotiation with relevant departments may be necessary). Therefore, a fire extinguishing system is not required by law, in principle. Nevertheless, for self-defense purposes, the experiment hall, the access halls, the transformer substation halls and the Klystron Tunnel will be equipped with fire-extinguishing systems.

Areas are subdivided into smaller local areas (safety-blocks) so as to be able to immediately deal with any accidents. The situation related to all safety and security issues will be monitored and displayed at the central security control center.

The safety system includes the following:

- **Fire-extinguishing system:** Since electricity is the most probable source of fire, systems based on chemical powder are the appropriate choices. The experiment and access halls are equipped with movable powder fire extinguisher systems or big fire extinguishers. The Main Tunnels are also equipped with fire extinguishers.

- **Fire alarm system:** Smoke alarms and thermo-alarms are placed in the tunnels. All information will be collected by receivers in each safety block.

- **Emergency Warning (Broadcasting) system:** All areas related to the GLC facility will be covered by a broadcasting system for an emergency. A broadcasting amplifier is to be located in each security block. Remote signal from the central system will be delivered through optical cables.

- **Emergency lights:** In the case of an emergency, DC electricity will be supplied through either main lines or secondary lines.

- **Radiation safety:** Radiation safety monitors must be equipped appropriately in the Klystron Tunnel and the Accelerator Tunnel, as well as the experiment hall. All information will be collected to the central radiation safety system. Access to the radiation-safety areas must be fully controlled by both the central and local systems.
- **Gas safety:** Gas safety systems must be made in the experiment hall.

Attention must be paid to radiation effects in the surroundings of the tunnels during accelerator operation. A simulation study has been conducted on this issue for radiation that originates from beam losses in the main linacs. The assumptions in this simulation included the following: (1) the center of 3mϕ tunnel is located at least 10 m deep underground, (2) the accelerator structures are set at the tunnel center, (3) the concrete wall of the tunnel is 30 cm thick, (4) the beam power is 8 MW, (5) the beam loss is 0.25%, which is uniformly distributed along the linac of 8900 m length and (6) the annual operation time is 5,000 hours.

It was found that the radiation dose on the surface ground above the tunnel will be 3 μSv/year, even in the case of relatively shallow tunnels. This estimated radiation dose corresponds to 0.2% of the natural radioactivity (1 $\sim$ 2 mSv/year). For deeper tunnels, the surface radiation dose will decrease exponentially. For example, the expected dose will be 10^{-5} μSv/year in the case of tunnels that are 20 m deep. In addition to beam losses within the accelerators, many muons will be created at the beam dumps. However, the radiation dose on the surface due to these muons will be substantially smaller. Simulation studies indicated that the radiation due to neutrons can be controlled to stay within a safe level, too. The activation of ground water is required to be lower than 10 μSv/year. This is also considered to be achievable.

In addition, the levels of radiation at the site boundaries will be measured by using monitor stations. The stations will be installed on the ground surface along the accelerator tunnel at intervals of a few kilometers. These monitors will be equipped with a stand-alone power supply based on solar cells and a wireless data-transmission system. This allows continuous monitoring of radiation levels at locations distant from the main campus without frequent needs for maintenance. The types of radiation to be measured are neutrons, photons and ionizing particles, such as muons, emitted during the operation of the GLC accelerators. The levels of radiations are surveyed online by the NORM (Network of Radiation Monitors) system, which will be newly designed for GLC. These measurements include monitoring the emissions of radioactivity in the air and in the water.

5.7 Process for Construction

The boring speed by TBM is normally 200–500 m/month/TBM machine, which greatly depends on the underground condition. One finds several examples of the recent boring in a granite rock area in Japan with the boring speed reaching to about 700 m/month. We assume that the condition of the construction site is sufficiently good to bore at a speed of 300 m/month/TBM machine. This is a reasonable assumption if the site is better than CM-class rock without encountering any major difficulty, such as a large area of delicate rock which needs subsequent countermeasures, in the boring regions. Once such a condition is satisfied, the tunnel needs only to be sprayed with concrete without any additional supporting mechanism in most of the areas inside the tunnel.

An overview on the whole process, from tunnel boring to alignment of the accelerator components, is shown in Fig. 5.11.

The first step of the tunnel boring is the excavation of the Utility and the Access Tunnels from ground surface to the Main Tunnels. While the duration of the excavation will depend on the length and the scheme of these tunnels, it will be completed in about a year. Through five out of seven Access Tunnels (AT1 $\sim$ 3, 5 $\sim$ 6), the TBM system will be installed and prepared for boring of the Main Tunnels. The current plan assumes 10 TBM to be operated simultaneously. At each section of the boring of the Main Tunnel, a pair of TBM will be used for constructing the double-tunnel structure.

The boring process by the TBM will take about two years for the Main Tunnels for the linacs and final focus sections. The excavation of the injector systems, mainly with NATM, will also be accomplished in the same period. As for an experiment hall, it will take about 3 years to complete the excavation. Note that there will be a large amount (> 100 m^3) of muck to be produced in the boring process, which will be removed through the Access and Utility Tunnels. Once the boring by TBM is completed for about a 2 km long section, an AT or UT to be used for muck removal will be switched to the next one. Then, the boring process for the 30 cm ϕ bore-holes will follow for the section to connect between the Klystron Tunnel and the Accelerator Tunnel. The ways to dispose or recycle the muck must be planned in detail before construction, which is one of the key elements for a speedy and steady construction.

A section having all boring procedures completed will be cleaned up. This is for subsequent processes including the installation of systems for electric power, cooling water and others. Eventually, when the floor in the tunnels is ready for the section, hardware devices, such as the accelerator units structure, RF devices and magnets, will be installed. Most of the elements are expected to be placed by the end of the 4th year of the construction period. An initial alignment of the accelerator units will be performed as described in Chapter 4. It is expected to take 5 years for the overall process of boring, installation, and the initial alignment.

The following additional considerations are necessary to further optimize the design and to shorten the engineering period:

- Procedure for muck transporting underground and on ground,
- Delivery system for the accelerator components in the tunnel,
- Installation procedures in detail, and
- Optimization of accelerator assembling method.

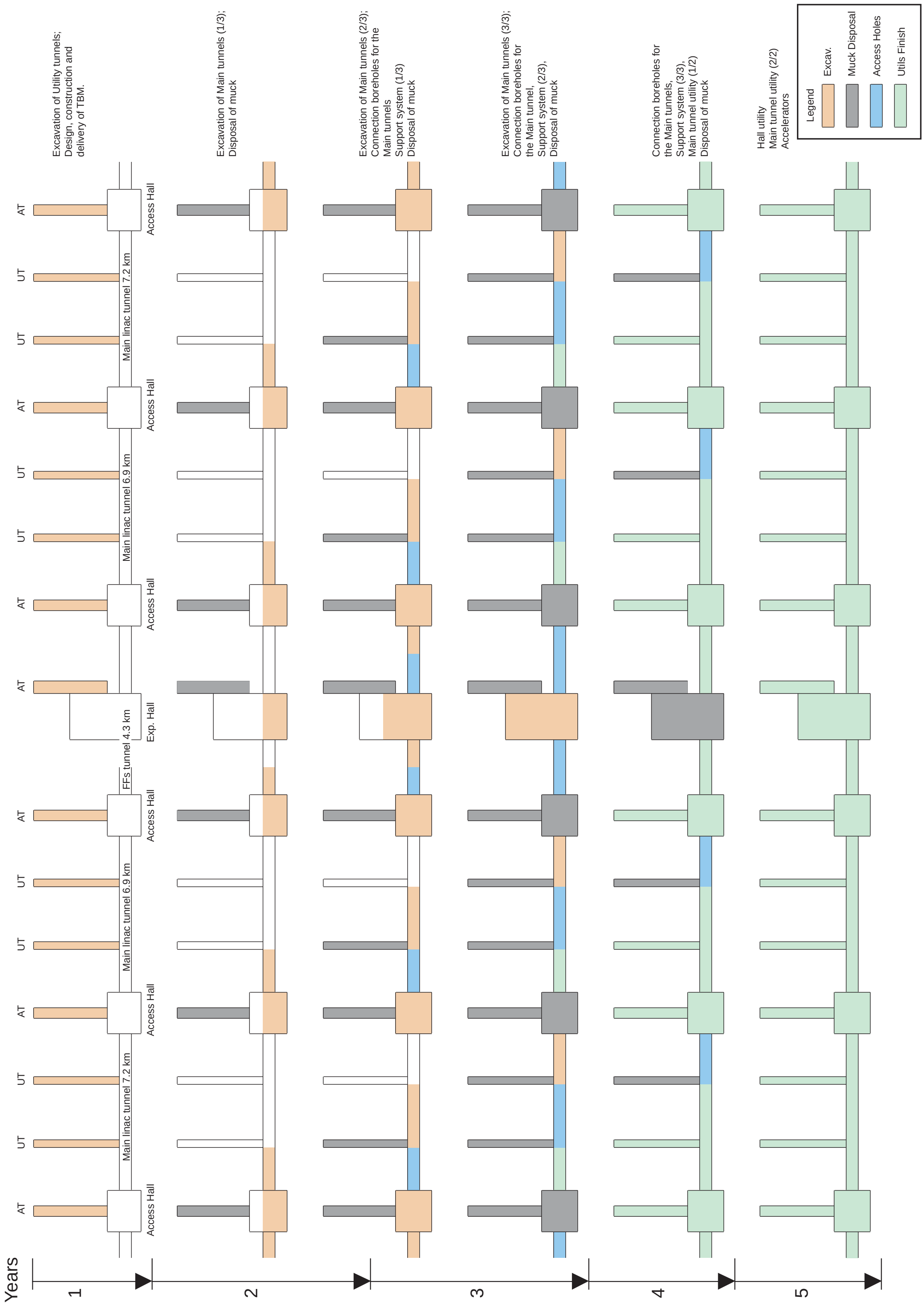

Figure 5.11: *Construction process.*