Chapter 5. Infrastructure

5.1 4GSR Infrastructure Overview

5.1.1 Introduction

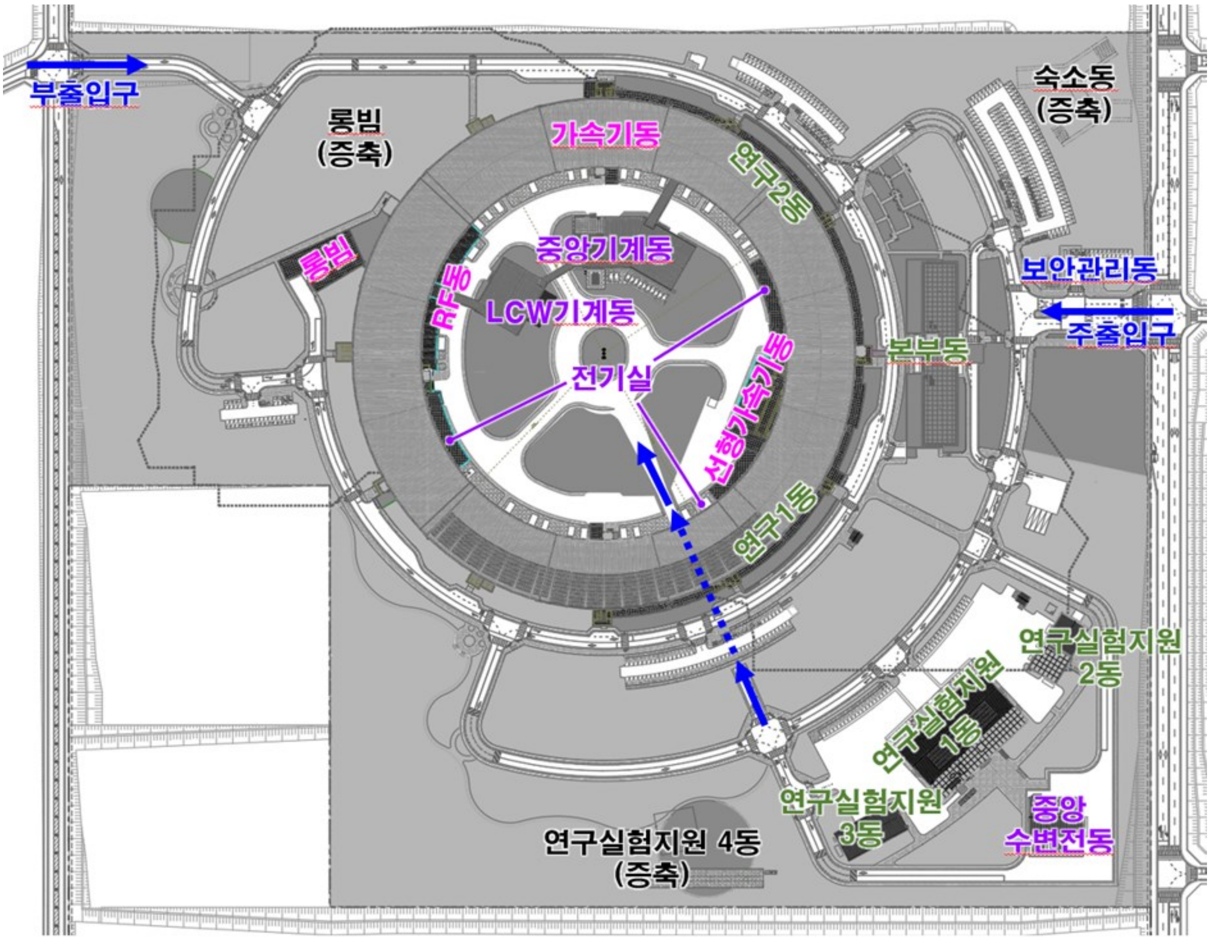
The infrastructure of 4GSR encompasses the buildings and utility systems essential for the installation and operation of various accelerator and beamline devices. It must be designed and constructed to ensure optimal accelerator performance, high stability, a safe, efficient, and comfortable research environment. Furthermore, project schedule, budget, and energy cost in the operational stage, and future development plans are considered. The beam stability in the 4GSR is significantly influenced by environmental variables such as LCW (low conductivity water) temperature, air temperature, vibrations and ground displacement, as well as the stability of individual devices comprising the accelerator and beamline. In particular, as vibrations and ground movements affect not only accelerator performance but also the operational schedule of device, through sufficient investigation, design, testing, and precise construction are imperative.

Accordingly, design activities for construction, air conditioning, cooling water supply, and power supply have been conducted. Following the presentation of the design concept and objectives in the CDR, the TDR provides a detailed summary of the specific infrastructure design.

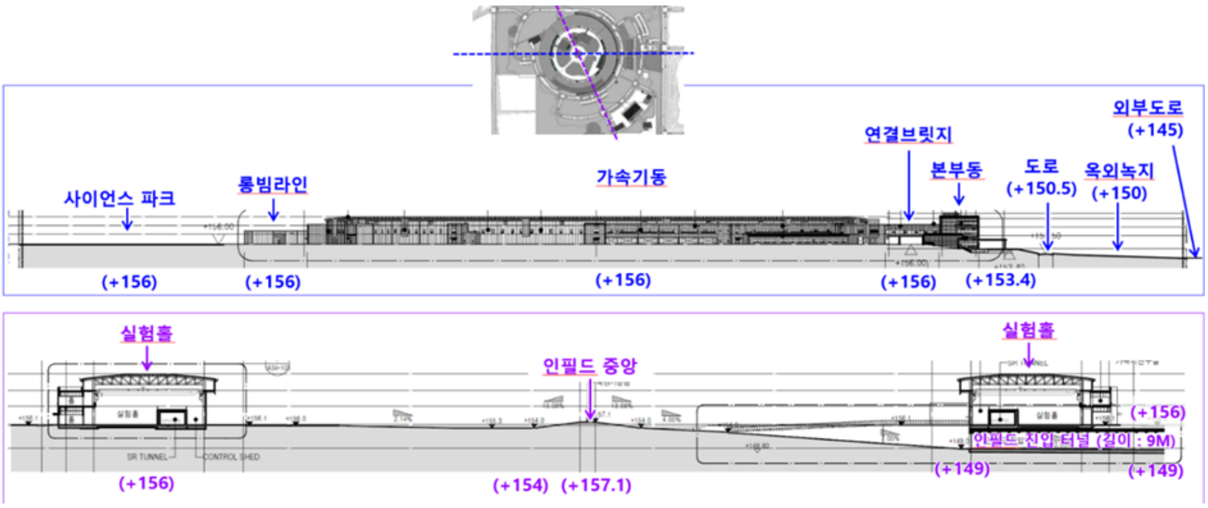
5.1.2 Layout

The 4GSR site covers an area of 540,000 m², comprising 310,000 m² of the basic site and 230,000 m² of the excess site. In this project, various facilities have been allocated to the basic site. The locations of the storage ring and long beam line were determined based on the results of an on-site geological survey, and their layout is shown in <Figure 5.1.2.1>. While the storage ring building is primarily conducted on cut rock, the experimental hall, located between the 6 o'clock and 8 o'clock positions from the center of the storage ring, lies outside the base rock, necessitating stable ground construction in certain sections. The total floor area of the building is approximately 69,000 m² (including the long beam line). The long beam line, research support building 4, and user accommodation building, which will be additionally constructed in the future, were reflected in the basic layout.

The main entrance is located on the east side of the site, while a sub-entrance is situated on the northwest side. The security management building is positioned at the main entrance. The starting point of the main entrance is at 148 m above sea level, and the bottom of the storage ring is 156 m above sea level. The northwest side of the site is mostly 156 m above sea level, and the terrain descends toward the east and south of the site. Electrical installations are conducted underground along the road on the east side, supplying power to the central waterside power building on the southeast side of the site. The floor of the central waterside power building is elevated approximately 1m above than the surrounding area to prevent flooding, even during heavy rain. The water supply facility is also planned to be installed along the road and connected to the business site.



<Figure 5.1.2.1> Site Layout for the 4GSR facility.



<Figure 5.1.2.2> Cross sectional view of the 4GSR land.

The Administrative building is located on the east side of the storage ring so that visitors can easily identify it from the main gate. It is a three-story building with a total floor area of approximately 7,500 m², designed for administrative functions, conference activities, and research purposes, including a conference room (main auditorium). The area extending from the entrance lobby to the auditorium is designed for exhibitions and informal meetings. A bridge connects the second floor of the Administrative building with the second floor of the storage ring building, providing convenient access.

The storage ring building consists of a tunnel and an experimental hall, with a total floor area of approximately 38,600 m². Since various accelerators and experimental devices are installed and operated in the tunnel and experimental hall of the storage ring, floor stability is critically important. Accordingly, the storage ring has been arranged so that most devices are installed on bedrock, based on the results of the ground investigation.

Buildings directly connected to the accelerator are positioned as possible to the devices, while research support facilities are located on the outskirts of the storage ring. Consequently, the Local Elec. Substations (1, 2, 3), the central machine building, the LCW Utility Building, the Linac building, etc., are placed within the storage ring infield, whereas the Administrative building, the R&D support building, and the gas storage building, etc., are located outside the storage ring. The user accommodation building, scheduled for future expansion, is situated on the northeast side of the site to enhance user accessibility. In addition, vibration-generating devices are installed as far away from the storage ring building as possible to minimize vibration transmission.

<Figure 5.1.2.3> Bird's eye view of the 4GSR facility.

5.1.3 Building Area

Considering the budget, the 4GSR building will be constructed during the first phase of construction as an essential structure for the installation and operation of the accelerator device, as indicated in <Table 5.1.3.1> below, and will be expanded as needed in the future. The total floor area to be built in the first phase is approximately 69,000 m^2.

<Table 5.1.3.1> Building size of the 4GSR facility

Classification		Area (m^2)	Total (m^2)
Administrative building		7,465	7,465
Storage Ring Bldg.	Storage Ring Bldg.	38,629	51,241
	Linac Bldg.	1,551	
	RF Bldg.	1,805	
	Local Elec. Substation1, 2, 3	2,156	
	Research Building 1, 2	7,100	
Central Utility Bldg., LCW Utility Bldg.		3,077	3,077
R&D Support Bldg. 1		5,470	5,470
R&D Support Bldg. 2		804	804
Main Power Substation		782	782
Security Management Bldg.		187	187
Total Floor Area			**69,026**

5.1.4 Utility

The water supply facility is designed to receive both tap water and industrial water, contingent upon the surrounding conditions. Industrial water is designed for the cooling tower, which is the largest water consumer. The inlet pipe diameters are specified as 100 A for tap water and 125A for industrial water.

Electrical power will be sourced via two 154 kV lines from the KEPCO Ochang Substation; one line is dedicated to permanent use while the other serves as a standby. The inlet power specifications are 154 kV, 40 MVA.

5.2 Buildings for Accelerators and Beamline Equipment

The accelerator and beamline buildings consist of the Linac building, the RF building, and the storage ring building, which includes an experimental hall. Since these structures house the accelerator, where both the accelerator is installed and operated and beamline experiments are conducted, environmental variables affecting beam stability must be stringently controlled, and both general safety and radiation protection measures must be ensured. The accelerator building features a truss structure designed to account for deflection and structural strength, and its foundation is a direct foundation installed on rock, as determined through a review of the ground investigation report.

Most accelerator devices are installed in the tunnel. Various control and monitoring devices for the storage ring and the MPS device are installed in the shed adjacent to the accelerator. The klystron, modulator, and other control devices for the linear accelerator are installed in the Linac gallery. As the linear accelerator system and RF system utilize high-power pulse power supplies, harmonic and EMI shielding are critical. Accordingly, transformers are segregated according to the characteristics of the devices, and appropriate measures—such as employing cable ducts for the power cables and surrounding signal lines—should be adopted. The beamline experimental preparation room is located on the perimeter of the experimental hall, spanning from the 12 o'clock to the 6 o'clock positions, with provisions for future expansion around the storage ring. An independent exhaust facility capable of safely removing hazardous gases used in the experimental preparation room and experimental hutch must be built for each beamline. This exhaust facility is to be installed in the duct room on the third floor of the storage ring, where the exhaust fan is located and the duct room is maintained under negative pressure to prevent harmful gases from leaking into the room.

Liquid nitrogen required for the beamline devices is supplied to each beamline via a pipeline by installing a tank in the 12 o'clock and 6 o'clock directions of the storage ring infield. Liquid nitrogen for sample cooling is provided from a liquid nitrogen supply station (LN2 filling station) located in the storage ring experimental hall, using a cylinder. A chemical storage room is located adjacent to the chemical cleaning room in R&D Support Building 2, and gas storage rooms are installed at two separate locations outside the storage ring to store various chemicals and gases.

5.2.1 Storage Ring Tunnel

The storage ring tunnel is a dedicated space where various devices for both the storage ring and booster ring are installed and operated. The configuration of the storage ring is illustrated in <Figure 5.2.1.1> and <Figure 5.2.1.2>. The tunnel should closely conform to the lattice structures of the storage ring and booster ring while providing adequate space for the installation and operation of the devices. Moreover, the devices must perform optimally within a stable environment and include effective radiation shielding personnel during accelerator operation. In order to meet these requirements, the following conditions must be satisfied.

○ The storage ring tunnel is constructed with a 1,000 mm thick foundation concrete to ensure that all devices remain securely positioned, and an additional 300 mm of steel fiber concrete is poured on top. The foundation concrete must be constructed with an appropriate connection method between successive pours to form a monolithic structure, and any volume changes during construction must be carefully accounted for to prevent deformations such as localized settlement.

○ The tunnel's floor, ceiling, and walls are constructed with concrete of appropriate thickness for radiation shielding. The thickness of the vertical concrete wall is approximately 500 to 700mm for the inner wall on the shed side of the storage ring tunnel; 800 mm at the non-injection area and up to 1,000 mm at the injection area for the wall on the experimental hall side; and 1,300 to 2,000 mm for the wall at the ratchet end. The tunnel ceiling is constructed with concrete approximately 500 to 700 mm thick in both the non-injection and injection areas. The thickness of the concrete shielding may be adjusted based on future radiation shielding analyses, and, if necessary, additional shielding will be installed in specific areas to ensure radiation safety.

○ During the first phase of construction, sliding shielding doors will be installed at 10 locations where beamlines will be installed to allow access between the tunnel and the experimental hall. The openings measure 1 m in width and 2 m in height. With future beamline expansions in mind, the construction design accommodates the potential for installing shielding doors in each cell.

○ The unloading areas are located at the 4 o'clock, 8 o'clock, and 12 o'clock directions outside the storage ring, and at the 3 o'clock, 6 o'clock, 9 o'clock, and 12 o'clock directions in the infield.

○ To transport equipment from the infield to the tunnel, an entrance for devices—accessible via the tunnel—is created adjacent to the unloading area. For transporting large goods, an entrance measuring 3 m in width and 3.5 m in height is provided at the 6 o'clock and 12 o'clock positions. Additionally, an entrance measuring 2 m in width and 2.5 m in height is provided at the 3 o'clock and 9 o'clock positions. The area designated for the large radiation shielding door is designed to accommodate the load, ensuring that the concrete floor remains stable under heavy objects.

○ The passages connecting the control shed to the tunnel are evenly distributed at 12 locations, serving as access routes for maintenance, inspection, and emergency escape from the tunnel. These passages are designed in a double-bend maze configuration to enhance radiation shielding.

○ In the tunnel, a trench is installed to channel water from any device leak to an external radiation management manhole. Additionally, a manhole is installed on the exterior of the building on the infield side.

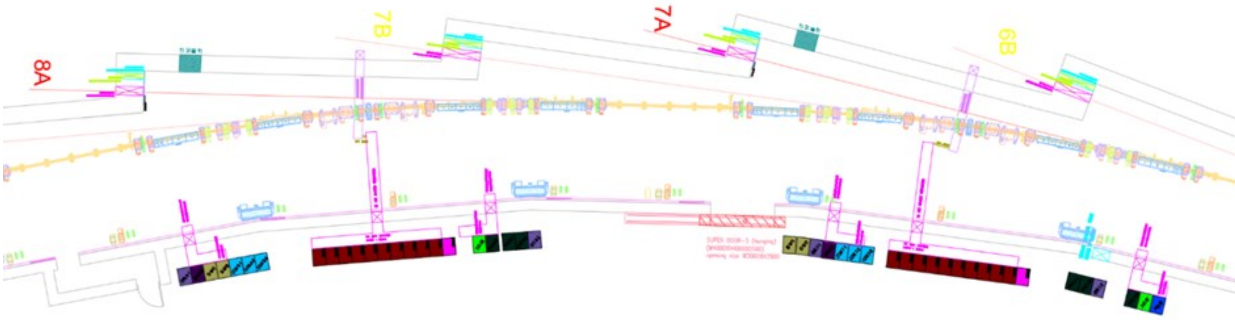
○ The beam center height of the accelerator is 1,400mm.

○ The tunnel floor is constructed using SFRC (steel fiber reinforced concrete) with a 300 mm thick overlay on the base concrete and is finished with an epoxy lining to prevent cracks, ensure flatness, and facilitate anchoring for device installation. This epoxy lining also minimizes fine dust generation in the tunnel, thereby aiding the installation and maintenance of vacuum devices.

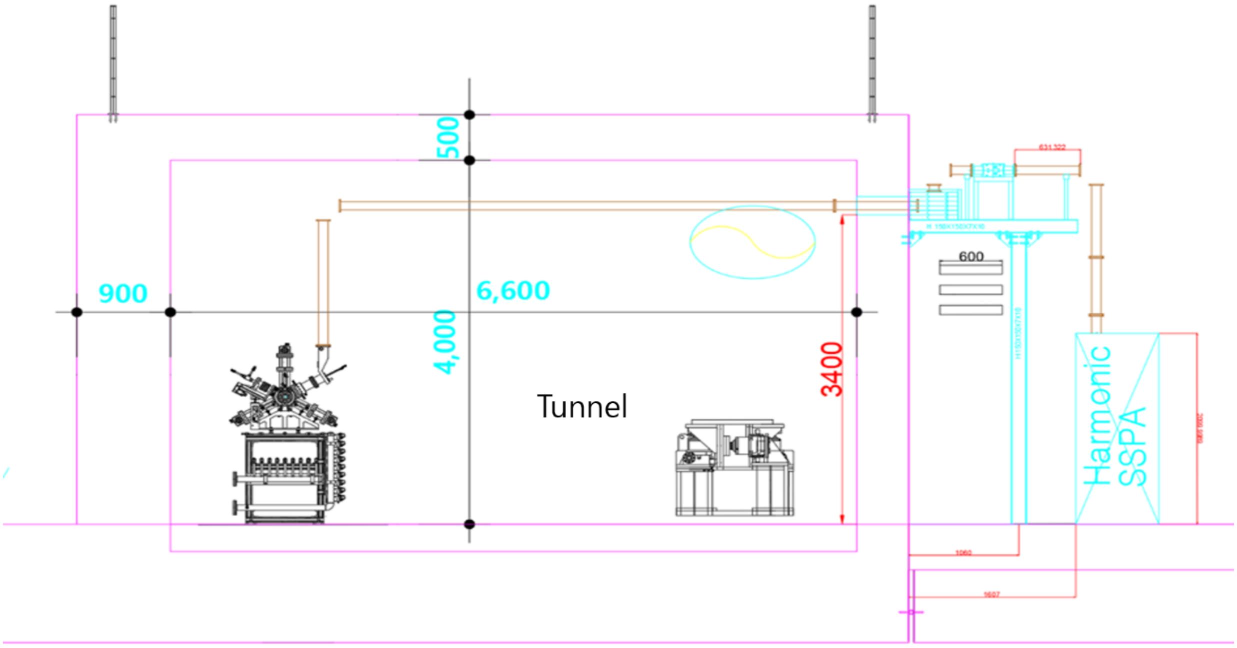
○ Diagnostic racks, MPS racks, and other similar equipment are installed in the storage ring shed.

○ Facilities—including LCW, air conditioning equipment, electrical equipment, and MPS cables—must be arranged so as not to interfere with the air conditioning flow.

○ To maintain the tunnel's air conditioning environment, the inflow of outside air is blocked, and the tunnel interior is kept under negative pressure.



<Figure 5.2.1.1> Plan view of the Storage ring tunnel.



<Figure 5.2.1.2> Cross-sectional view of the Storage ring tunnel.

5.2.2 Tunnel Mezzanine

Utility pipes—including LCW, compressed air, and liquid nitrogen—are installed along the upper portion of the tunnel, with MPS rooms constructed above the pipes in certain areas. Consequently, provisions must be made to ensure that personnel can easily access these areas and that equipment can be transported when necessary. The following structures need to be considered:

○ Install LCW, air pressure, and LN2 pipes on the upper part of the tunnel.

○ Install a diagnostic beamline along the upper portion of the tunnel.

○ Install an MPS room for Septum electromagnets, Kicker electromagnets, etc. at the 3 o'clock position on the upper portion of the tunnel. The MPS rooms may be installed individually or integrated, depending on the equipment characteristics.

○ Install two stairways/passages providing access to the upper portion of the tunnel in the beamline experiment hall, eight in the control shed, and one on each bridge.

○ Install an elevator and stairs for access from the storage ring infield loading area to the tunnel. The elevator should have a minimum capacity of 2 tons or more to transport both cargo and personnel.

5.2.3 Experimental Hall and Access Corridor

The experimental hall is the area where various beamlines are installed and where users are located. As additional beamlines will be continuously installed, equipment can be transported via the corridor outside the experimental hall. Beamline equipment is installed using a crane. Given the frequent entry and exit in this area, double doors are installed at the entrance to maintain an optimal air-conditioning environment.

○ The experimental hall is where the beamline is constructed and experiments are conducted. It is a space where various beamlines and hutches are installed and users reside.

○ The width of the experimental hall is determined by assuming the beamline length to be 80 m in the tangential direction from the center of the storage ring's long straight section (tunnel interior ≤25 m, experimental hall ≤55 m).

○ The outermost part of the experimental hall shall include a passage with a minimum width of 2.5 m to allow for the movement of forklifts and personnel.

○ A passageway shall be provided on the experimental hall floor in two areas where beamlines cannot be installed, and a staircase connecting the experimental hall to the tunnel shall be installed.

○ The inflow of outside air is blocked to maintain the experiment hall's air conditioning environment.

○ The experimental hall is designed to accommodate the future construction of a long beamline extending outside the building.

○ The height of the beamline device shall be 1,400 mm, and the concrete floor for each beamline shall be structurally monolithic.

○ The floor of the experimental hall shall be 300 mm thick SFRC (steel fiber reinforced concrete) poured over the base concrete and finished with an epoxy lining to prevent cracks, ensure flatness, and facilitate anchoring for device installation. This epoxy lining shall also help minimize the generation of fine dust, thereby aiding the installation and maintenance of vacuum devices.

○ A clear line-of-sight for beamline device alignment shall be secured.

○ A passageway for equipment and personnel to access the beamline shall be secured around the beamline.

○ An independent exhaust facility shall be installed for each beamline.

○ Liquid nitrogen required for the beamline device shall be supplied to each beamline via a pipeline by installing a tank in the storage ring infield.

○ Liquid nitrogen for samples shall be supplied from a liquid nitrogen supply station (LN2 filling station) in the storage ring experimental hall using a cylinder.

○ A passage connecting the liquid nitrogen supply facility to the experimental hall corridor shall be secured.

○ Two hoist cranes (3 tons) shall be installed in the experimental hall for installing various beamline devices and hutches.

○ Facilities for high-ceiling work shall be provided, such as a mobile work platform (crane type) with a work deck platform (deck), to facilitate the maintenance of ceiling lights or other equipment.

5.2.4 Linac Building

The Linac Building comprises an assembly and preparation room for performing klystron assembly and preparation, electron gun preparation, and accelerating column testing; a tunnel in which the accelerator is installed; and a gallery housing the K&M (klystron & modulator) and control and monitoring devices.

○ The beam center height of the linear accelerator device is 1,400 mm, similar to that of the storage ring.

○ The tunnel floor is constructed by pouring a 300 mm thick layer of SFRC (steel fiber reinforced concrete) over the foundation concrete and finished with an epoxy lining.

○ The location of the waveguide penetration hole connecting the gallery to the tunnel is incorporated into the design.

○ Power cables, control cables, RF cables, etc., connecting the gallery to the tunnel are routed through trenches, and LCW and compressed air are conveyed through holes that penetrate the shielding wall.

○ In the tunnel, trenches, manholes, drainage pumps, etc., are installed to channel water to external radiation management manholes in the event of device leakage.

○ The tunnel and gallery are environments in which temperature and humidity are strictly controlled. Consequently, they are designed to minimize the influence of outside air. External entrance doors are installed on both sides, with a corridor approximately 3 m wide, to block the inflow of outside air.

○ The tunnel is maintained under negative pressure to prevent airborne radionuclides from leaking out. The air conditioners in the gallery and device areas are designed to prevent air from mixing with the research/office spaces.

○ The gallery device can be installed and disassembled using an electric forklift (2.5 tons), necessitating a corridor width of approximately 6 m. Cranes are not installed in the gallery.

○ The klystron assembly and preparation room must be equipped with a 5 ton crane that has a lifting height of 5 m to enable tasks such as replacing the insulating oil in the klystron tank.

○ An insulating oil storage facility shall be located near the klystron assembly and preparation room.

○ A gas storage facility capable of storing nitrogen and helium is installed near the linear accelerator (for use with RF units).

5.2.5 RF Building

The RF building is a two-story structure that houses facilities for the storage ring and boosting RF cavity. The control room is situated at the center of the building, with RF amplifiers installed on both sides. A waveguide connects to the storage ring tunnel via the mezzanine, and the building's air conditioner is installed internally.

○ The RF Building comprises HPRF Room 1, HPRF Room 2, and the Control Room.

○ A multi-level structure is implemented for the installation of waveguides, and a hoist (2 tons) is installed on this multi-level to transport equipment.

○ Entrances and exits shall be appropriately positioned to facilitate the movement of equipment and personnel.

○ The area designated for the control rack shall feature an access floor, while the remaining space shall have a concrete floor.

○ A ladder connecting the HPRF Room to the multi-level shall be installed.

○ Air conditioning equipment for the RF Building shall be installed within the RF Building.

5.3 Research and Support Facilities

5.3.1 Administrative Building and Auxiliary Facilities

A. Administrative building

The Administrative building is designed for administrative functions and meetings. It is situated opposite the main entrance, enabling visitors to the research institute to easily identify it, and is surrounded by a spacious parking area. A bridge connects its second floor to the storage ring building, facilitating easy access. The headquarter building comprises the following sections:

○ A conference room with a capacity of approximately 400 people.

○ A lobby for simple refreshments and exhibitions is located at the entrance of the Administrative building.

○ In front of the conference room, a designated area is provided for participant registration, relaxation, and informal discussions.

○ The first floor comprises a lobby, conference room, small conference room, break room, preparation room, building management office, and restrooms.

○ he second floor is connected to the storage ring building by a bridge to provide easy access.

○ The third floor comprises an area for collections, visiting researchers, conference rooms, and meeting rooms.

○ Each floor is equipped with a medium-sized conference room and a breakout room.

B. Research Building

○ The research building is situated on the outskirts of the storage ring. For future expansion, four research buildings are planned in the design phase; among these, Research Building 1 and Research Building 2 are constructed in the initial phase and are positioned at the 2 o'clock and 4 o'clock orientations relative to the storage ring.

○ The research labs and offices are situated in close proximity to facilitate convenient access to various devices.

○ The entrance to the research building includes a space where users can rest or engage in informal conversations.

○ Access from the research building to the storage ring is provided via a double door, designed to prevent disruption to the storage ring's air conditioning environment.

○ High-risk research labs that handle toxic substances are equipped with independent exhaust systems.

○ The research labs and offices are equipped with individual heating and cooling systems.

○ An HVAC system is implemented in common areas, such as hallways.

C. R&D Support Building

○ R&D Support Building 1 serves as a space for testing and assembling various accelerators and beamline devices. It features a large, high-ceiling area, with the outer wall divided into two levels to accommodate laboratories. This expansive area is partitioned to support the assembly and experimentation of accelerators and beamline devices, with provisions for future modifications. The first floor of the laboratory area is designated as a laboratory that does not require a high ceiling. The basement of R&D Support Building 1 is fully equipped with a power distribution board and LCW supply facilities. A 20-ton overhead crane is installed to handle operations throughout the building's large space, and a door is provided to allow the entry and exit of large trailers.

○ R&D Support Building 2 is designated for housing chemical cleaning rooms, radiation analysis rooms, and for storing various chemicals and radiation waste; exhaust facilities and other necessary facilities for the safe storage and handling of chemicals are installed.

○ R&D Support Building 3 (magnetic field measurement room) requires a stable air conditioning environment and isolation from vibrations to ensure accurate measurement and safe storage of electromagnets and insertion devices. In addition, a 20-ton crane will be installed to facilitate the movement of heavy objects.

D. Utility Building

○ 4GSR's utilities are broadly divided into power and water supply.

○ Electricity is supplied at 154 kV from the KEPCO substation, then stepped down to 22.9 kV at the Main Power Substation. From there, it is distributed to the transformers of the Administrative building, R&D Support Building 1, and STR 1 and STR 2 in the Storage Ring infield. The electrical equipment in the Administrative building powers the building itself, the electric vehicle charging facilities in the parking lot, the security management building, and future dormitory buildings. The electrical equipment in R&D Support Building 1 supplies power to both the R&D Support Building and the Main Power Substation. The STR in the Storage Ring infield is divided into two units—one for the accelerator and one for general power—with a tie device installed between them to ensure continued accelerator operation even if one STR fails. A UPS for equipment requiring uninterruptible electricity can supply power for 15 minutes, and one 1,000 kW and one 400 kW emergency generator are installed as backup power sources.

○ Water is provided from both tap water and industrial water sources; industrial water is used for the cooling tower, while the remainder is used as domestic water. A water tank of appropriate capacity is installed to prepare for potential water shortages.

○ The LCW Utility Building produces LCW for devices and supplies it to the storage ring, experiment hall, etc. LCW supply facilities and refrigerators are constructed in R&D Support Building 1 to provide LCW for device testing in that building and to supply the cold water required for R&D Support Building 3. R&D Support Building 2 is equipped with its own LCW production facility for chemical cleaning.

○ The utility monitoring system is installed in the control room of the Central Utility Building and supplies PV values to the accelerator operation room.

E. Main Power Substation

The Main Power Substation is a building designed to receive 154kV electricity from KEPCO, step it down to 22.9kV, and distribute it via installed facilities. The main transformer is located outdoors, while the other distribution panels are installed indoors. The building must have a minimum height of 5 m. Appropriate air conditioning facilities are provided to ensure the safe operation of the distribution facilities. The SCADA system for power system monitoring is installed in the Central Utility Building. A 5-ton crane is installed in the indoor space housing the GIS facilities.

F. Local Elect. Substation

Local Elect. Substations 1, 2, and 3 are located in the storage ring infields adjacent to the accelerator load. The STR for the accelerator is installed outdoors at Local Elec. Substation 1, while the STR for general power is installed outdoors at the Central Utility Building. Electrical rooms are also located in the Administrative building and R&D Support Building 1, and these rooms are equipped with appropriate air conditioning facilities to ensure the safe operation of the power distribution equipment.

G. Central Utility Building, LCW Utility Building

The building for utility machinery equipment is divided into the Central Utility Building and the LCW Utility Building. The Central Utility Building produces hot and cold water to provide the living water required for each building and device, and it supplies hot and cold water to the air conditioning equipment located within the infield. This building is equipped with water supply facilities, firefighting facilities, air conditioning facilities, and compressed air facilities, and it includes a control room for remote monitoring and control of emergency generators and utility equipment (mechanical, electrical).

The LCW Utility Building produces cooling water (LCW) for devices using tap water and supplies it to each accelerator and beamline device. Since the Machinery Building, which generates significant noise and vibration, is located away from the accelerator and experimental hall devices, its placement minimizes interference with sensitive equipment.

5.4 Structural Engineering and Mechanical Engineering

5.4.1 Building Design Load

The roof and exterior walls of a building must be designed with sufficient consideration of local snowfall, wind speed, rainfall, and other environmental factors. When installing air conditioners on a building's roof, both the load capacity and the vibration impact must be carefully evaluated. The seismic design standard for 4GSR buildings is set at 0.25g for storage ring buildings and 0.22g for other buildings. The design load for the building floor is detailed in <Table 5.4.1.1>.

<Table 5.4.1.1> Design load of the building floor

Location	Load (kg/m²)
Laboratories	610
Experimental Hall	1,220 (to be confirmed in the final design)
Ring Tunnel	1,220 (to be confirmed in the final design)
Tunnel mezzanine	610
Ring Building access corridor	610 (or wheel loads from forklift trucks)
Corridors	500
Stairs and lobbies	500
Offices	500 (includes 100 kg/m² for partitions)
Light storage areas	610
Mechanical rooms	730 (or actual weight of equipment)

5.4.2 Smoothness and Allowable Displacement of the Linac Tunnel, Storage Ring Tunnel, and Experiment Hall Floor

The linear accelerator tunnel, storage ring tunnel, and experimental hall house the accelerator and beamline devices, making the smoothness and displacement control of the concrete floor critically important. The relative and absolute positions of the accelerator and beamline devices are essential; if these positions fall outside the acceptable range, accelerator operation must be halted and realignment performed. Consequently, both the vertical and horizontal displacements of the ground are key factors in the accelerator's performance and operation. Prior to pouring the floor concrete for the tunnel and experimental hall, a geological survey must be conducted and an appropriate construction method determined to ensure foundation stability and to verify ground stability through sufficient testing. The displacement of the foundation ground is influenced by variations in groundwater level, temperature, and other factors.

The smoothness of the concrete floor for device installation is equally important. To secure the required flatness, after pouring the base concrete, a 300 mm thick layer of steel fiber reinforced concrete (SFRC) is poured on top, ensuring not only flatness and crack prevention but also facilitating the installation of anchors for various supports. The initial flatness requirement for the concrete floor was set at within 10 mm across the entire surface; however, based on the architectural designer's input regarding increased construction management costs, this requirement was adjusted to 25 mm. To compensate for this deviation, grouting or shims will be applied during support installation. The flatness and vertical displacement allowances for the storage ring tunnel, experimental hall, and linear accelerator tunnel are detailed in <Table 5.4.2.1>.

<Table 5.4.2.1> Smoothness and vertical displacement allowance of storage ring tunnel, experimental hall, and linear accelerator tunnel

Smoothness of floor	< 10 mm / 10 m
	< 10 mm / floor
Long term settlement-vertical	< 100 ㎛ / 10 m / year
	< 10 ㎛ / 10 m / day
	< 1 ㎛ / 10 m / hour

5.4.3 Vibration Standards

The allowable vibration standards for the experimental hall are closely tied to the research equipment used by beamline users. The vibration standards for both the experimental hall and the storage ring tunnel floor are rigorously enforced according to VC-E or higher, with reference to general scientific research equipment and XFEL guidelines.

<Table 5.4.3.1> Vibration Standards of the Experimental Hall and the Storage Ring Tunnel Floor

Static Load		< 6 ㎛/ 0m @ 500 kg/
		< 1 ㎛/ 2m @ 500 kg
Dynamic Load		1 ㎛/ 2m @ 100 kg (ptp)
Vibration (0.1 to 70 Hz)	**Induced by facility**	< 1 ㎛ (ptp)
	Added to the external effects	< 4 ㎛ (ptp)
	Vertical	< 1 ㎛ (ptp)
	Horizontal	< 4 ㎛ (ptp)

5.4.4 Noise Standards

The primary sources of noise are those produced by infrastructure—such as air conditioning and cooling water systems—and those generated by users' research equipment, including pumps and chillers. While noise from research equipment can be managed on a case-by-case basis, noise from infrastructure must be addressed during the design phase. Infrastructure noise is controlled by regulating airflow speed, managing cooling water flow, and employing sound-absorbing materials. The noise standards for major areas are detailed in <Table 5.4.4.1>.

<Table 5.4.4.1> Noise criteria for each building part

Space	Type Noise Criteria (NC) Level
Office	35 to 40
Laboratory	45 to 50
Conference rooms	30
Interaction space	40
Common use areas	40 to 45
Accelerator tunnel Non-Experimental Hall	60 to 65
Mechanical / Electrical rooms	Application of safety management standards
Seminar room	30

5.4.5 Mechanical Devices

Each building must be equipped with the water supply, air conditioning, and ventilation equipment necessary for daily operation. The Administrative building, Research Building, and R&D Support Building utilize individual air conditioning and heating systems. The area where the accelerator device is installed and R&D Support Building 1 use central air conditioning. The Linear Accelerator Gallery, Storage Ring Tunnel, and R&D Support Building 1 must be equipped with independent air conditioning and ventilation systems. The Linear Accelerator Tunnel maintains a stable environment via its inherent design without an air conditioner. The Long beam line requires a precisely controlled air conditioning environment. It is separated from the Experiment Hall and maintains an air conditioning environment of 25℃ ± 5℃. The Long beam line hutch is equipped with an independent air conditioning facility as necessary. The required air conditioning environment for the building is as shown in <Table 5.4.5.1>.

<Table 5.4.5.1> Air conditioning environment of the building

Storage Ring Tunnel	25 ℃ ± 0.1 ℃, humidity 60% or less
Experimental Hall	25 ℃ ± 0.5 ℃, humidity 60% or less
RF Building	25 ℃ ± 1 ℃, humidity 60% or less
Office, Laboratory	25 ℃ ± 5 ℃, humidity 45% to 70%
Long beam line Experimental Hall	25 ℃ ± 0.5 ℃, humidity 50% or less

Pipelines should be installed on the Storage Ring Mezzanine to supply liquid nitrogen and dry compressed air to each beamline. A filling station capable of supplying liquid nitrogen should be installed in the Experimental Hall. The liquid nitrogen tank is located in the infield. The Linear Accelerator, RF Building, Storage Ring Tunnel, and Experiment Hall are supplied with LCW from the LCW Utility Building in the infield. R&D Support Buildings 1 and 3 are supplied with LCW from separate facilities located in R&D Support Building 1.

5.5 Mechanical Facilities

The mechanical facilities comprise LCW supply equipment, air conditioning equipment, water supply equipment, compressed air equipment, and firefighting equipment. LCW supply equipment is a device that produces LCW, controls its temperature and pressure, and distributes it to various devices. It comprises a triple loop connected to cooling towers, chillers, and heat exchangers, and regulates the temperature of the LCW by controlling the flow rate of chilled water entering the heat exchangers LCW supply facilities are divided into two categories: those for accelerators and beamlines, and those for supporting research experiments. LCW supply facilities for accelerators and beamlines are installed in the LCW Utility Building in the infield, while those for supporting research experiments are installed in the machine room on the first basement floor of R&D Support Building 1. The air conditioning area is divided into two sections: a precision air conditioning area for accelerator and beamline devices, and a general air conditioning area that includes offices and laboratories. For precision air conditioning zones, operation is managed centrally using air conditioners, maintaining an air temperature of approximately 25℃ ± 0.1℃. Within the general air conditioning area, offices and laboratories are served by individual cooling/heating devices and total heat exchangers, whereas common areas—such as hallways and lobbies—are centrally managed with air handling units and FCUs.

The HVAC system employs five 750 usRT turbo chillers and two 360 usRT absorption chillers, while the LCW system utilizes four 1,000 usRT turbo chillers. Cooling towers and chilled water/cooling water pumps are installed to match the chillers' capacity. Major equipment—including chillers, cooling towers, pumps, and control valves—is designed with at least one standby unit to accommodate failures and is configured as a system capable of year-round operation.

The building for mechanical equipment is divided into two sections—the LCW Utility Building and the Central Utility Building—and is located in the infield area. The LCW Utility Building houses the LCW supply equipment for various devices, while the Central Utility Building accommodates the hot and cold-water supply systems for air conditioning, firefighting equipment, and building water supply. The LCW Utility Building is located near the RF Building, while the Central Utility Building is situated between 12 o'clock and 1 o'clock—adjacent to the LCW Utility Building—to ensure convenient equipment operation. Both buildings are also located near high-load areas to reduce the power required for heat medium transport and lower equipment construction costs.

Air conditioners are installed in the infield area, close to the air conditioning zone, to facilitate maintenance and repair. Since vibrations from rotating equipment in the machinery building and air conditioners can affect beam operation, vibration reduction measures must be incorporated into their design.

Daily water usage is expected to reach up to 1,000m^3, while the water supply pressure is maintained at 1.5kgf/cm^2 or higher. Considering the water supply capacity at the 4GSR site, the cooling tower utilizes industrial water. The water tank size is determined in accordance with the 'Regulations on Building Standards'. A water tank with an appropriate capacity is constructed to ensure stable operation of both the 4GSR and domestic water systems, and the water supplied to the cooling tower is monitored via an installed flow meter.

5.5.1 LCW System

The LCW supply facility comprises a triple loop connected to cooling towers, refrigerators, and heat exchangers, and regulates the LCW temperature by controlling the flow rate of the cold water supplied to the heat exchanger. The temperature of the LCW supplied from the LCW Utility Building is maintained with an accuracy of 25℃ ± 0.1℃, while the linear accelerator constitutes a system that can supply LCW from 27 to 33℃ ± 0.1℃ as needed.

The LCW system is configured as a closed-loop, designed to maintain the temperature of accelerator and beamline devices at a constant level. It is prohibited to use the LCW system for purposes such as cooling a furnace or cleaning a device, as these applications may affect the temperature and properties of the LCW. To prevent contact corrosion between dissimilar metals and to accommodate LCW pressure requirements, device locations, and load characteristics, the LCW supply circuit is divided into four independent operational units.

To prevent device corrosion and electrical accidents in the event of LCW leakage, LCW with a resistance value of 6㏁·㎝ or greater is supplied. The Water-Treatment system and Mixed-Bed Device are used to produce LCW and maintain its purity. The Water-Treatment system receives tap water, produces pure water, and supplies LCW to four separate cooling water circuits. The Mixed-Bed Device captures ions and foreign substances generated during the LCW circulation process to maintain and enhance LCW purity. The operating status of the mechanical equipment, along with the temperature, pressure, and resistance values of the LCW, is stored and monitored via a network in the Central Machine Operation Room.

A. System requirements

○ LCW serves as the medium for cooling the heat generated by accelerators and beamline devices.

○ The supply temperature of LCW is maintained with a precision of 25 ± 0.1°C.

○ The electrical resistance value of LCW is maintained at 6 ㏁·㎝ or higher.

○ The supply pressure of LCW is categorized into two levels: 8 kgf/cm² for high-pressure and 5 kgf/cm² for low-pressure.

○ To prevent corrosion caused by contact between dissimilar metals on the LCW-contacting load side, separate LCW circuits are designated for copper and aluminum components.

○ To remove impurities from LCW, the system is configured such that 5% of the flow passes through the Mixed-Bed System.

○ If a unit device requires a temperature higher than the standard LCW temperature (25℃ ± 0.1℃), individual heaters and heat exchangers should be applied to that unit.

○ All LCW machinery and equipment can be operated and monitored remotely, supplying LCW-related data—such as temperature, pressure, flow rate, and purity—to the Storage Ring Operation Room.

○ All products in the Storage Ring Tunnel are manufactured using radiation-resistant materials.

B. System Configuration

(1) LCW Supply Plan

○ LCW is supplied in four types, as detailed in <Table 5.5.1.1>, based on supply location, load-side material, supply pressure, etc.

○ The load-side metals in contact with LCW include copper, aluminum, and stainless steel. Separate LCW circuits are supplied for copper and aluminum, whereas no restrictions apply when the load-side metal is stainless steel.

<Table 5.5.1.1> LCW Supply Chain Composition

Types of LCW	Supply Pressure(kgf/cm²)	Load-side Metals	Supply Location and Key Equipment	Heat Load of Equipment (kW)	LCW Circulating Flow Rate (㎥/h)
HP(Cu)	8	Cu, STS304	Tunnel, Magnet, Chamber	1,562	351
LP(Cu)	5	Cu, STS304	E/H, Shed, Linac	3,131	616
LP(Al)	5	Al, STS304	Tunnel, Chamber	196	67
RF(Cu)	5	Cu, STS304	RF building, Tunnel, RF Cavity	5,126	879

○ The total cooling capacity of LCW is 10,015 kW, designed based on the maximum heat generation of each device.

○ The total circulation flow of LCW is 1,913 m^3/h, with a bypass line configured to control the flow based on the device load.

○ The heat and flow rate for each device supplied with high-pressure (Cu) LCW are presented in <Table 5.5.1.2>.

<Table 5.5.1.2> High-pressure (Cu) LCW heat capacity and flow rate

Operating Location	Equipment Name	Heat Load of Equipment (kW)	LCW Circulating Flow Rate (㎥/h)
SR Tunnel	SR Magnet	956	121.3
	Booster Magnet	381	77.2
	SR Chamber_Cu	29	10.1
	SR Mask	98	33.6
	Photon Absorber	98	33.6
	Harmonic Cavity	Including SSPA	43.2
	Booster Cavity	Including SSPA	32.4
Total		**1,562**	**351.4**

○ The heat and flow rate for each device supplied with low-pressure (Cu) LCW are presented in <Table 5.5.1.3>.

<Table 5.5.1.3> Low-pressure (Cu) LCW heat capacity and flow rate

Operating Location	Equipment Name	Heat Load of Equipment (kW)	LCW Circulating Flow Rate (㎥/h)
E/H	Beamline	2,127	372.0
Shed	SR MPS Rack	273	100.0
	BR MPS Rack	100	34.5
	Harmonic HPRF from 1 to 6	240	41.4
Linac Tunnel	Magnet	20	3.0
	ACC	10	7.2
	Wave Guide	-	6.0
	Gun	1.0	1.2
	Laser	-	-
Klystron Gallery	Modulator	360	45.0
	Constant temperature Rack	-	6.0
Total		**3,131**	**616.3**

○ The heat and flow rate for each device supplied with low-pressure (Al) LCW are presented in <Table 5.5.1.4>.

<Table 5.5.1.4> Low-pressure (Al) LCW heat capacity and flow rate

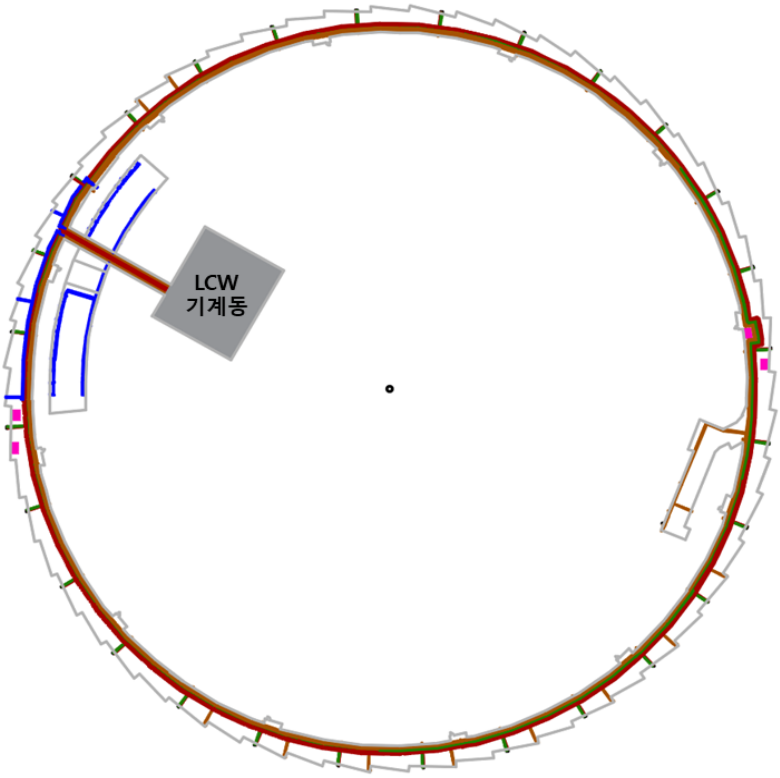
Operating Location	Equipment Name	Heat Load of Equipment (kW)	LCW Circulating Flow Rate (㎥/h)
SR Tunnel	SR Chamber	69	23.5
	ID Chamber	29	10.1
	BPM Chamber	98	33.6
Total		**196**	**67.2**

○ The heat and flow rate for each device supplied with low-pressure (Al) LCW are presented in <Table 5.5.1.4>. Heat and flow rate of each device supplied with RF(Cu) LCW are shown in <Table 5.5.1.5>.

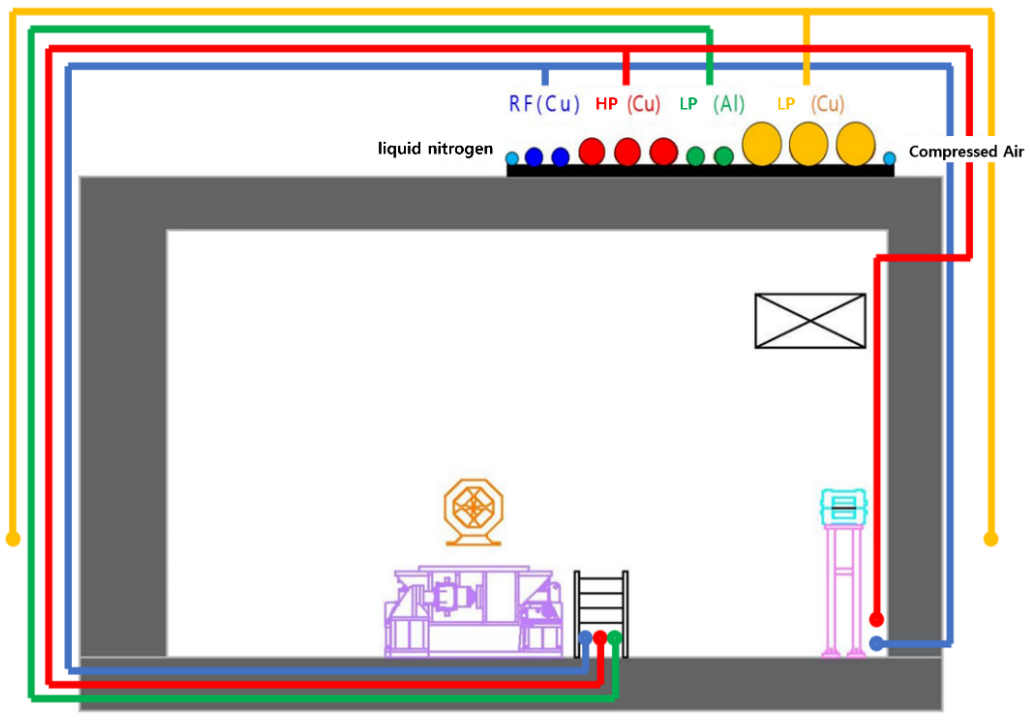
<Table 5.5.1.5> RF(Cu) LCW heat load and flow rate

Operating Location	Equipment Name	Heat Load of Equipment (kW)	LCW Circulating Flow Rate (㎥/h)
SR Tunnel	SR Cavity	Including SSPA	103.0
HPRF Room1	150kW SSPA from 1 to 4	1,400	130.8
	180kW Load from 1 to 4	Including SSPA	60.0
	Booster HPRF from 1 to 3	576	75.6
	Booster Load from 1 to 3	Including SSPA	45.0
	RF Test Facility	350	58.0
HPRF Room2	150kW SSPA from 5 to 12	2,800	286.2
	180kW Load from 5 to 12	Including SSPA	120.0
Total		**5,126**	**878.6**

○ The LCW pipe is connected to the RF Building and the upper part of the tunnel via a common duct that links the LCW Utility Building and the Accelerator Building, as illustrated in <Figure 5.5.1.1>. A total of 14 pipes pass through the common duct in the LCW Machine Building, and the configuration installed in the upper part of the tunnel is depicted in <Figure 5.5.1.2>.

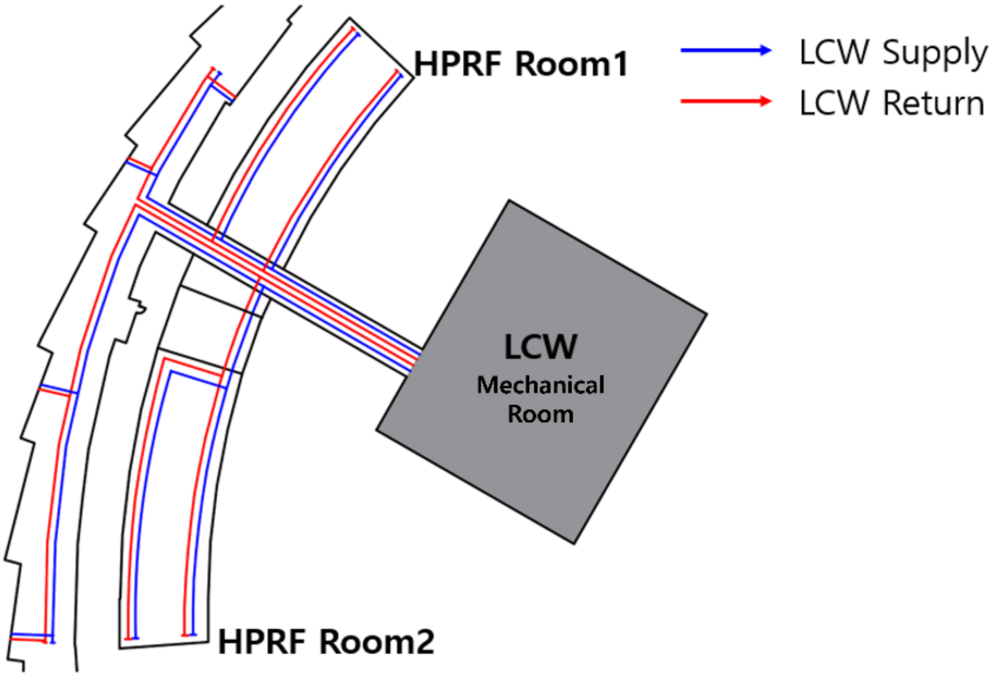


<Figure 5.5.1.1> Plan view of the LCW pipe on top of the tunnel.



<Figure 5.5.1.2> Cross-sectional view of the LCW pipe on the top of the tunnel.

RF(Cu) LCW piping is installed using the direct return method, as illustrated in <Figure 5.5.1.3>, and is divided into two sides around a central common pipe to accommodate the flow rate. RF(Cu) LCW is supplied to devices including SSPA, RF Load, and RF Cavity.

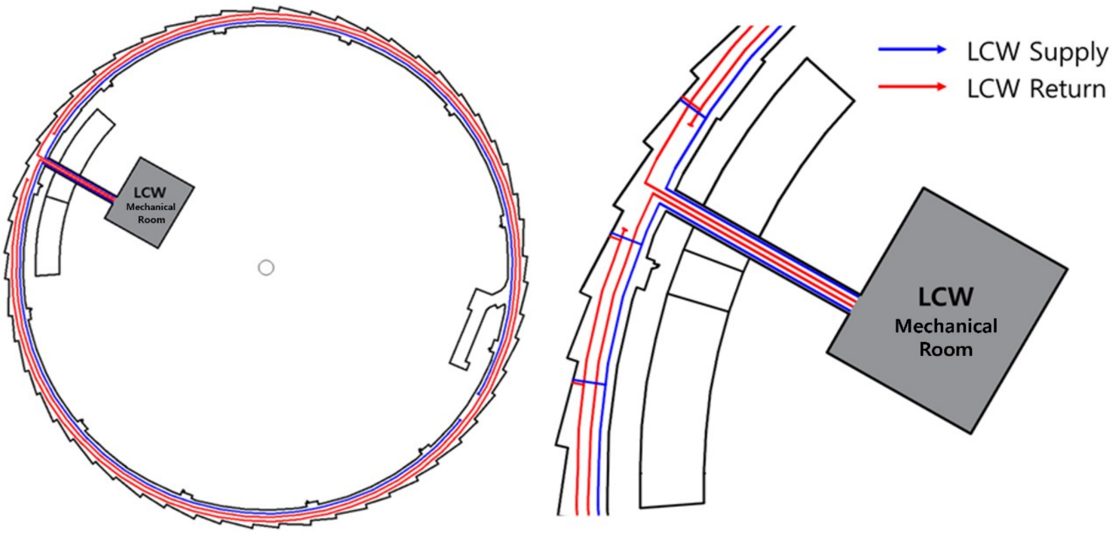


<Figure 5.5.1.3> Plan view of RF(Cu) LCW piping.

○ High-pressure (Cu), low-pressure (Cu), and low-pressure (Al) LCW piping utilize the reverse return method.

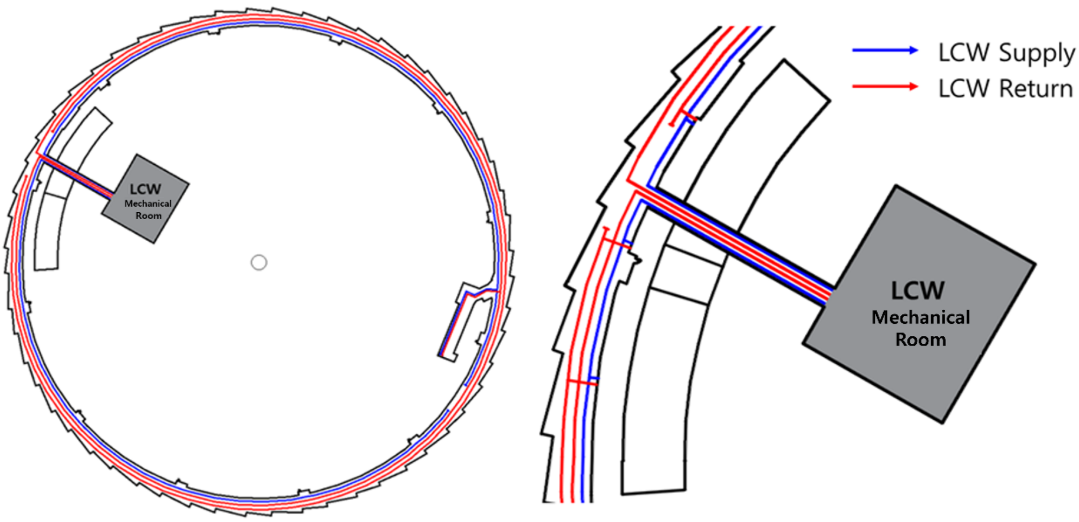
○ High-pressure (Cu) and low-pressure (Cu) LCW piping are divided into two sides around a central common duct, considering both the flow rate and piping length.

○ High-pressure (Cu) LCW piping is configured as illustrated in <Figure 5.5.1.4>.



<Figure 5.5.1.4> Plan view of high-pressure (Cu) LCW piping.

○ Low-pressure (Cu) LCW piping is configured as illustrated in <Figure 5.5.1.5>.



<Figure 5.5.1.5> Plan view of low-pressure (Cu) LCW piping.

○ Since the low-pressure (Al) LCW pipe has a low flow rate, it consists of one supply pipe and one return pipe, as illustrated in <Figure 5.5.1.6>.

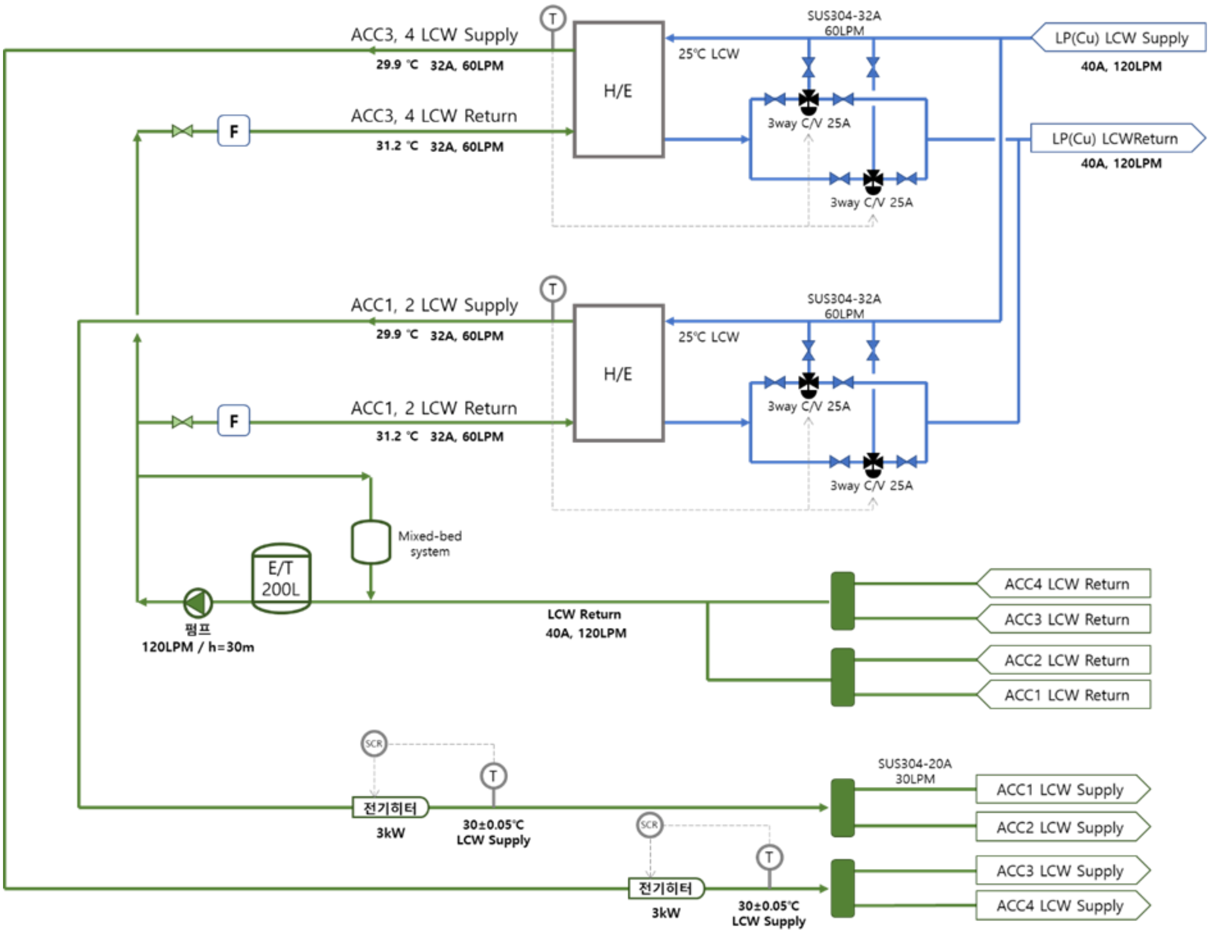
○ Three types of LCW are supplied to the Storage Ring Tunnel: high-pressure (Cu), low-pressure (Al), and RF (Cu). High-pressure (Cu) LCW is primarily provided to the storage ring and booster magnet, while low-pressure (Al) LCW is delivered to the aluminum vacuum chamber. RF (Cu) LCW is supplied to the storage ring and booster cavity.

○ Low-pressure (Cu) LCW is supplied to the beamline, control shed, Linac Tunnel, and Klystron Gallery.

○ During the operational stage of a unit device, such as during a test run, there may be instances where cooling water is supplied to only a subset of devices. In such cases, bypass piping should be appropriately installed to prevent pump overloading.

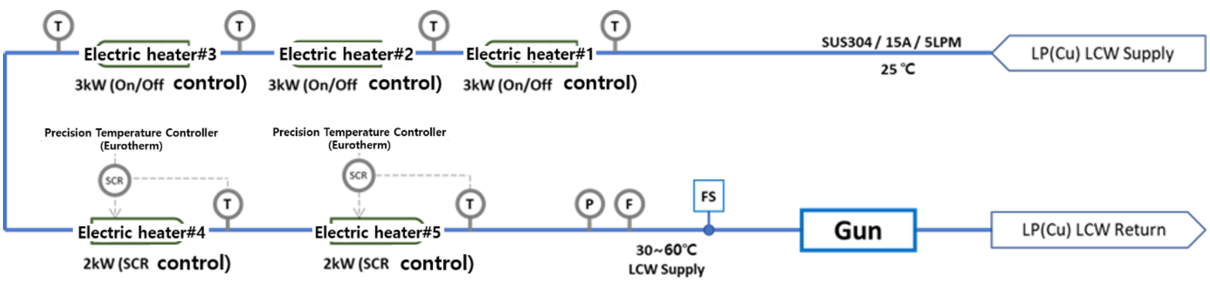
○ For devices that require LCW at a temperature higher than the supply temperature (25℃ ± 0.1℃), individual heat exchangers and heaters are installed to control the LCW temperature.

The linear accelerating column is equipped with a system capable of varying the temperature by ±3℃ from the standard temperature of 30℃ ± 0.1℃ as needed. For this purpose, a single closed-loop system is implemented, as illustrated in <Figure 5.5.1.6>. The heat generated in the accelerating column is dissipated via a heat exchanger using low-pressure (Cu) LCW at 25℃, and the LCW delivered to the accelerating column is precisely temperature-controlled through SCR-regulated electric heaters.



<Figure 5.5.1.6> LCW system diagram for accelerating column.

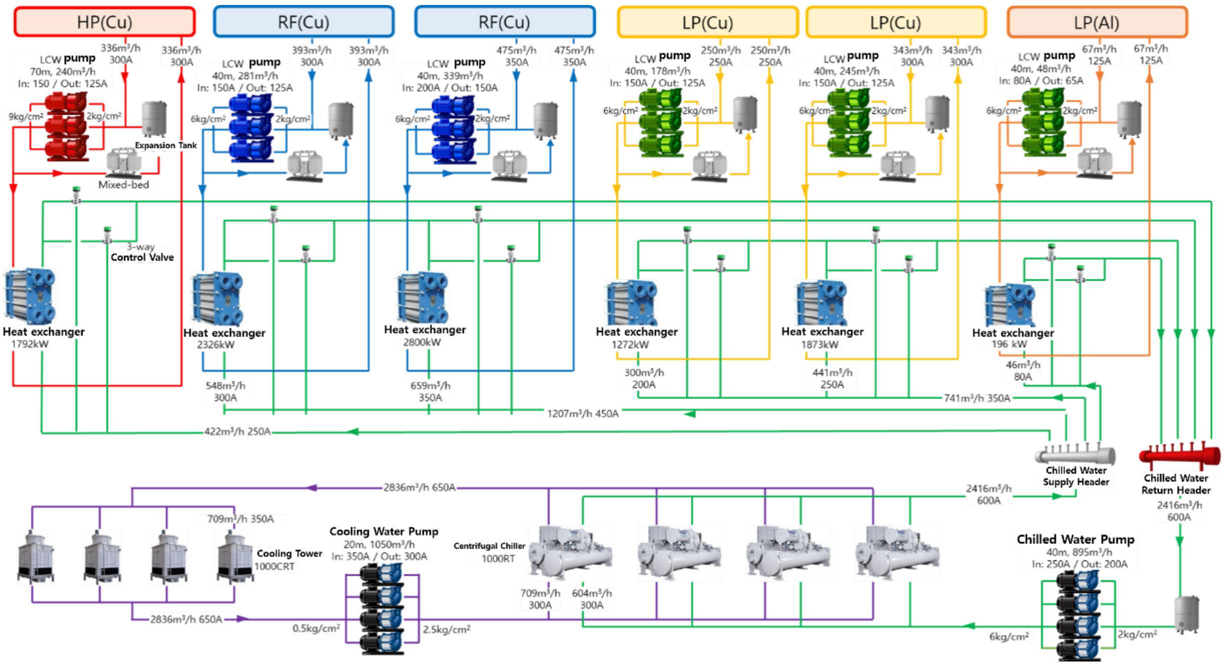
○ The LCW system for the linear accelerator electron gun is designed to be adjustable from 30℃ to 60℃. Accordingly, the electric heater is configured as illustrated in <Figure 5.5.1.7>. The low-pressure (Cu) LCW, initially at 25℃, is heated using an SCR-controlled electric heater. Its temperature is precisely regulated prior to supply and then returned to the low-pressure (Cu) return pipe.



<Figure 5.5.1.7> LCW schematic diagram for Linac electron gun.

(2) LCW mechanical equipment

○ LCW supply equipment comprises refrigerators, cooling towers, heat exchangers, pumps, etc., as illustrated in <Figure 5.5.1.8>.



<Figure 5.5.1.8> LCW machine equipment schematic diagram.

○ All equipment for LCW supply can be monitored and controlled via the Central Machine Operation Room, and process values (PV) are provided to the Storage Ring Operation Room.

○ Considering the flow rate of each system, the LCW circulation pumps are configured as follows:

- High-pressure (Cu): 3 units×1 set
- RF (Cu): 3 units×2 sets
- Low-pressure (Cu): 3 units×2 sets
- Low-pressure (Al): 3 units×1 set
- In each set, two pumps operate continuously while one pump serves as a standby.

○ The LCW circulation pumps are composed of three units per set—including one standby unit—considering the flow rate of each system. Specifically, high-pressure (Cu) is configured as one set, RF (Cu) as two sets, low-pressure (Cu) as two sets, and low-pressure (Al) as one set. In each set, two pumps operate continuously while one pump serves as a standby unit.

○ LCW pumps are selected as either single volute or vertical pumps, with a design power consumption of 100 kW or less, considering ease of maintenance.

○ The refrigerator will be a turbo chiller, comprising four units with a refrigeration capacity of 1,000 usRT each. Based on the maximum heat generation of the accelerator and beamline, three units will operate continuously while one unit will serve as a standby.

○ The cooling tower is selected as an open cross-flow cooling tower, comprising four 1,000 CRT units to match the chiller's cooling capacity. These four cooling towers are designed for continuous operation, with their fans controlled by an inverter to adjust to seasonal changes in outside temperature.

○ The cooling tower is installed adjacent to the LCW Machine Building.

○ The cold water produced in the turbo chiller is supplied to each heat exchanger via the cold-water supply header and is circulated back to the refrigerator at a constant pressure through the return header and expansion tank.

○ The heat exchanger employs a plate-type, gasket-type design and comprises a total of six units: 1 high-pressure (Cu), 2 RF (Cu), 2 low-pressure (Cu), and 1 low-pressure (Al). The capacity of the heat exchanger is selected based on the flow rate and cooling load of each system.

○ To control the LCW temperature, two three-way control valves are installed in the cold-water pipe at the outlet of the heat exchanger. One valve operates continuously, while the other serves as a standby. In the event of a valve failure or during maintenance, the remaining valve ensures normal temperature control.

○ A temperature sensor is installed in the LCW pipe at the outlet of the heat exchanger, and the opening of the three-way control valve is regulated to ensure that the LCW temperature at the outlet remains at 25°C ± 0.1°C.

○ To minimize pressure fluctuations in the LCW, one expansion tank is installed for each LCW system. Considering the differential pressure on the load side, the expansion tank's internal pressure is set within the target range of 1 to 2 kgf/cm^2 and maintained at a constant level using compressed air. The capacity of the expansion tank is determined based on the volume of LCW contained in each system's piping.

○ All materials for equipment through which LCW flows are made of stainless steel (STS304), with a pipe thickness of SCH10.

○ Cold water and cooling water equipment shall be constructed from galvanized steel or stainless steel, with a pipe thickness of SCH10.

○ The LCW, cold water, and cooling water pipes in the LCW Machine Room are designed with specifications that match the facility's capacity and provide an appropriate flow rate to prevent noise, vibration, and corrosion due to erosion.

○ Vibrations generated by LCW pipes installed atop RF Buildings and Storage Ring Tunnels may affect the equipment; therefore, the flow velocity within the pipes must be maintained below 1.5 m/s.

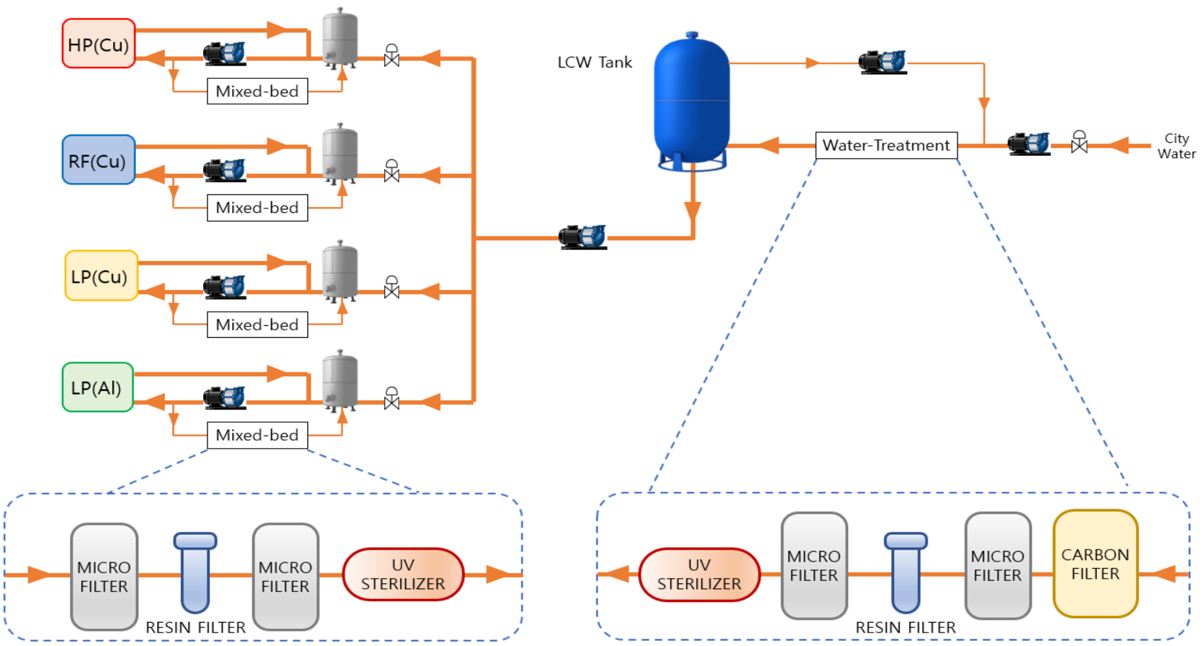
○ Facilities such as LCW, cold water, and cooling water systems are insulated with rubber foam, and outdoor-exposed pipes are finished with insulation protection sheets.

○ To ensure smooth supply and control of LCW, sensors are installed at appropriate locations to monitor temperature, pressure, flow rate, and purity.

(3) Water-treatment system

○ LCW stands for Low Conductivity Water, and foreign substances and ions must be removed from tap water to maintain a resistance value of 6 MΩ·cm or higher. To produce LCW and maintain its purity, a system is configured as illustrated in <Figure 5.5.1.9>.

○ Assuming the tap water pressure is 3 kgf/cm², if the pressure falls below this value, operate the pump to maintain it above 3 kgf/cm². The water-treatment system comprises, in sequence, a carbon filter, microfilter, ion resin filter, and UV sterilizer.



<Figure 5.5.1.9> Schematic diagram of the Water-treatment system.

○ Carbon filters remove organic substances from tap water, while microfilters remove fine particles. Ion resin filters, composed of cation and anion exchange resins, eliminate ions in the water. Additionally, a microfilter is installed downstream of the ion resin filter to prevent resin granules from passing through. UV sterilizers are used to eliminate microorganisms.

○ The water treatment system is designed to supply more than 3 m³/h, and the produced LCW is stored in an LCW tank.

○ The LCW tank is designed to have a capacity of 4 tons, and the water level shall be maintained at 80% at all times to ensure that LCW can be supplied without loss of purity even if replenishment is required due to leakage, etc.

○ To prevent deterioration of the LCW purity inside the tank, the piping and pumps are configured so that the LCW circulates continuously through the water treatment system.

○ An expansion tank is installed for each of the high-pressure (Cu), RF (Cu), low-pressure (Cu), and low-pressure (Al) circuits, with the internal pressure maintained at 1 to 2 kgf/cm^2. When the water level in the expansion tank falls below 70%, a solenoid valve automatically opens to supply LCW from the LCW tank; once the water level reaches 70%, the valve automatically closes.

○ High-pressure (Cu), RF (Cu), low-pressure (Cu), and low-pressure (Al) LCW are kept separate, with each system incorporating its own mixed-bed system. This mixed-bed system circulates approximately 5% of the LCW flow rate to maintain purity and remove foreign substances.

C. Field-specific facility plan

(1) Machinery and piping

○ The refrigerator employs a turbo chiller that utilizes R-134a in compliance with environmental regulations.

○ All pump motors are selected as 4-pole motors, taking noise and vibration into consideration.

○ Devices that generate vibrations are installed on a concrete base floor with appropriate vibration isolation devices.

○ An automatic air vent is installed in the upper section of the piping system.

○ Teflon is applied to the gasket at the connection joints.

○ A 40-mesh strainer is installed in front of the LCW, cold water, and cooling water pumps.

○ A drain line is installed to connect with the drainage channel.

○ The LCW supply pipe is insulated with 19T, while its return pipe remains uninsulated. In contrast, both the cold-water supply and return pipes are insulated with 25T, and the cooling water supply and return pipes are insulated with 19T.

○ The welding joints of the pipes are TIG welded; however, no nitrogen or argon purge is applied inside the pipes during welding.

○ Cooling towers are equipped with heaters to prevent freezing during winter.

(2) Electrical

○ For safety, high-voltage motors must be operated manually only on-site.

○ High-voltage panels include protective equipment such as VCBs and are installed in the Electrical Room.

○ The refrigerator starter unit is installed adjacent the refrigerator.

○ Cooling tower cables are routed through cable ducts.

(3) Instrumentation

○ A monitoring and control facility are installed in the Central Utility Building Operation Room to enable continuous monitoring and control of temperature, pressure, flow rate, electrical resistance, etc.

○ PV values, including temperature, pressure, and flow rate of the LCW, must be provided to the Storage Ring Operation Room.

○ UPS power is supplied to the monitoring and control equipment of the facility.

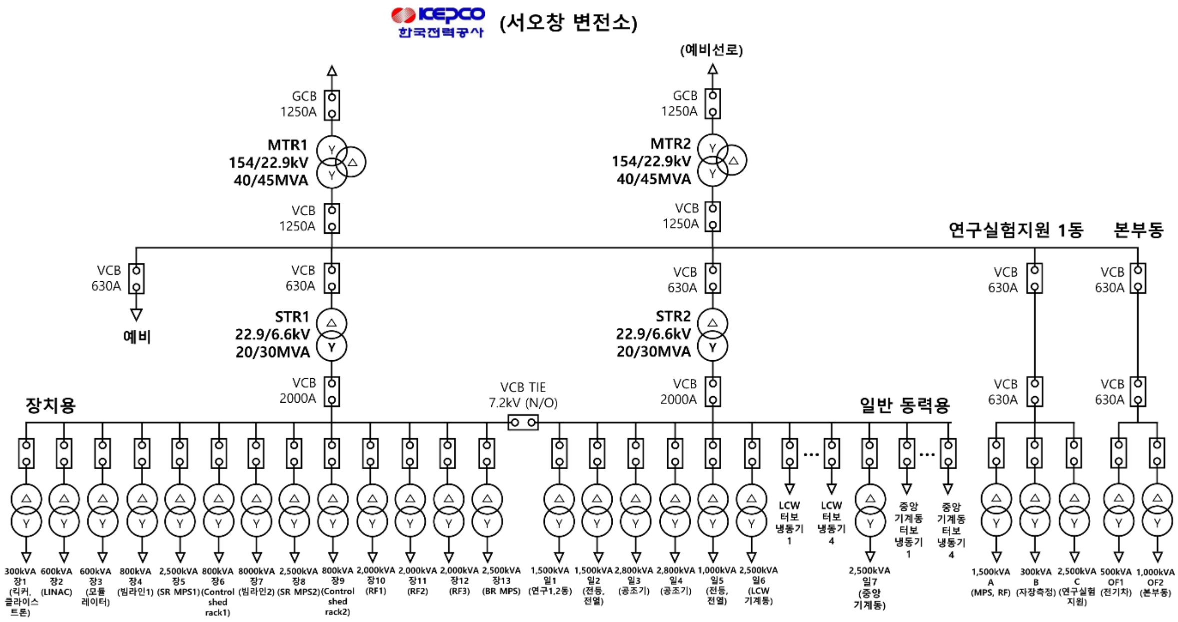
○ An electric three-way control valve is used, and both the output and input signals are displayed on the monitoring system.

○ Cooling tower fan motors are inverter type.

○ The refrigerator is programmed to allow all statuses to be monitored from the Central Machine Operation Room, and start/stop operations to be performed remotely.

5.6 Electrical Facilities

The electrical facilities of 4GSR comprise power distribution, emergency power, lightning protection, and grounding systems, etc. In consideration of stable power demand and supply, as well as future load increases, 154 kV is received via two circuits from the Seo-Ochang Substation through underground lines to the Main Power Substation. The contracted power capacity is 40 MVA. The power system of 4GSR is configured as illustrated in <Figure 5.6.1.1>.



<Figure 5.6.1.1> 4GSR single line diagram.

Electricity is stepped down to 22.9 kV by two MTRs and distributed via two circuits to the Storage Ring Infield, one circuit to R&D Support Building 1, and one circuit to the Administrative Building. STR1 is installed outdoors at Local Elec. Substation1 for the accelerator, while STR2 is installed outdoors at the Central Utility Building for general power. The voltage is further reduced to 6.6 kV by two STRs, which supply the transformers in Electrical Rooms 1, 2, and 3. The turbo chillers are directly connected to the 6.6 kV supply from STR2. The modulator transformer steps down 6.6 kV to 480 V to supply power to the load, whereas the remaining transformers reduce 6.6 kV to 380 V. The Local Elec. Substation of the Main Building and R&D Support Building 1 steps down 22.9 kV to 380/220 V to supply power to each building, and R&D Support Buildings 2 and 3 receive 380 V/220 V from the Local Elec. Substation of R&D Support Building 1.

<Table 5.6.1.1> 4GSR operating voltage

Classification	6,600V	480V	380/220V
Wiring method	3-phase 3-wire	3-phase 4-wire	3-phase 4-wire
Load type	High-voltage rotating equipment	Modulator	Power, lighting, heating, etc.

5.6.1 Electric Power Distribution Facilities

The substation facilities comprise two Bay 154 kV gas-insulated switchgear (GIS) and two 154 kV transformers (MTR1 and MTR2) located in the Main Power Substation. Both 154 kV transformers are installed outdoors in the Main Power Substation and are each connected on a 1:1 basis to the GIS. One circuit serves as a spare; therefore, if KEPCO inspects one circuit or a problem occurs, power can be supplied through the alternate line. Note, however, that a power outage occurs during the switching process. After being stepped down to 22.9 kV by the 154 kV transformer, the voltage is routed via cables to the HV panel in the Local Elec. Substation of the Main Power Substation to supply power to the subsystem.

For stable GIS operation, the manufacturer recommends performing regular, detailed inspections on an alternating three-year cycle. MTR1 and MTR2 employ Y-Y-△ wiring to eliminate third harmonics and are equipped with an oil gas analyzer that monitors gas generated from transformer insulating oil for early detection of transformer failures.

The distribution facility consists of transformers, panels containing circuit breakers and protective relays, and distribution boxes. This equipment is critical for ensuring the stability and reliability of the power system.

The rear busbars of STR1 and STR2 are connected by a bus tie that is normally open to isolate the system. However, in the event of an accident—such as the failure of one transformer—the bus tie is short-circuited so that power can be supplied to the entire load using a single STR.

STR1 is installed outdoors at Local Elec. Substation1 and supplies electricity to thirteen 6.6 kV transformers for the accelerator and beamline. Among the loads, devices that generate harmonics and noise are segregated from other equipment to minimize their impact. In particular, SVC (Static Var Compensation) and AHF (Active Harmonic Filter) are installed behind the transformers serving loads such as the modulator, klystron, and MPS to counteract harmonics and noise, while SC (Static Condenser) is installed behind the remaining transformers to improve the power factor and reduce voltage drop and losses.

STR2 is installed outdoors at the Central Utility Building and is connected to seven 6.6 kV transformers as well as turbo chillers for air conditioning and LCW equipment. The transformers for the Central Utility Building and LCW Utility Building are housed in the Local Elec. Substation of the Central Utility Building, and pumps constitute the main loads.

Rotating devices, such as motors, generate starting currents that are 5 to 6 times their rated capacity; therefore, an appropriate starting method must be selected to avoid impacting other equipment.

The load capacity required for each device was evaluated and classified into loads required for accelerator operation and maintenance, and transformer capacity was calculated as shown in <Table 5.6.1.2>.

<Table 5.6.1.2> 4GSR transformer configuration

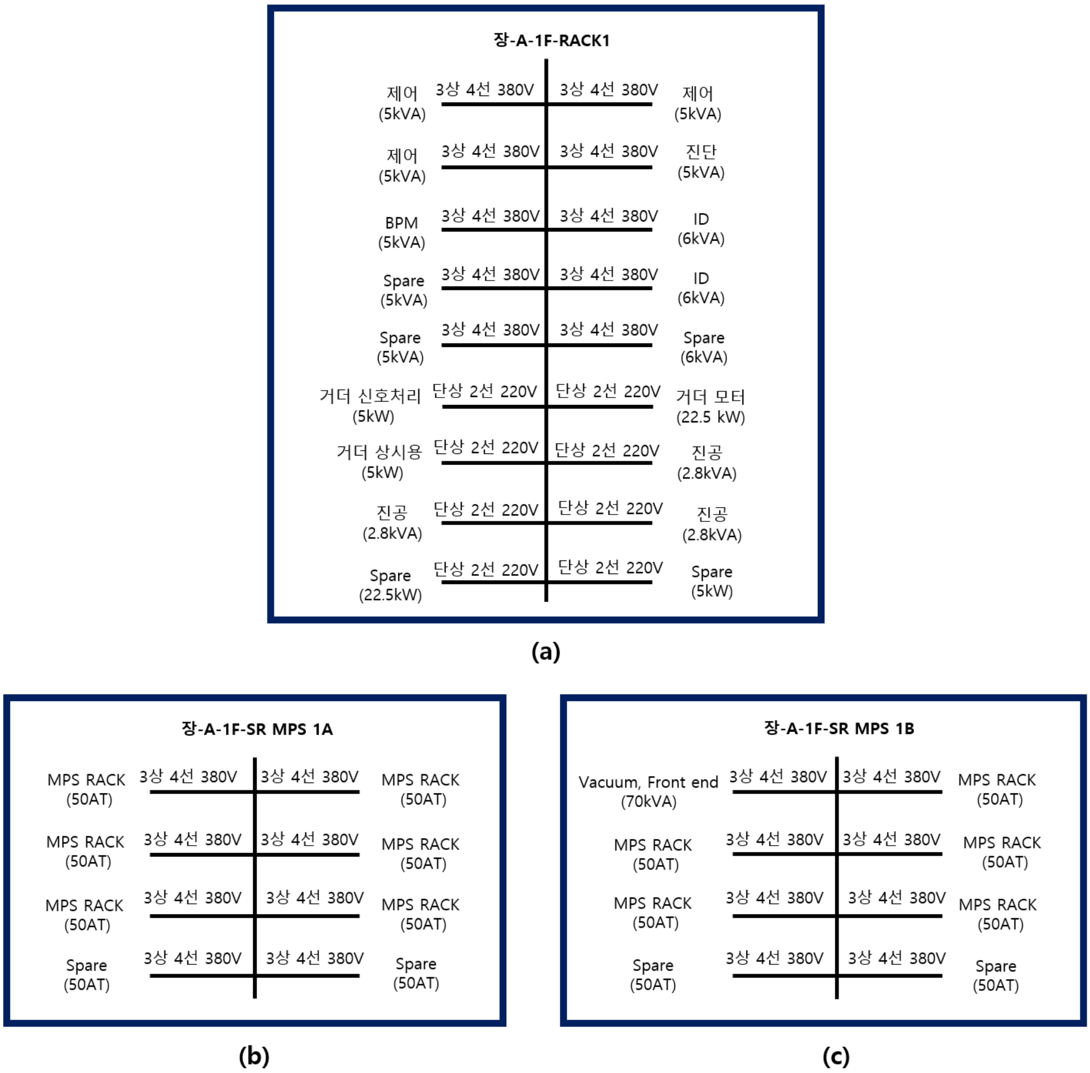
No.	Transformer location	Transformer name	Type	Input voltage (V)	Output voltage(V)	Transformer capacity (kVA)
1	Main Power Substation	MTR1	Oil	154,000	22,900	40,000
2	Main Power Substation	MTR2	Oil	154,000	22,900	40,000
3	Local Elec. Substation1	STR1	Oil	22,900	6,600	20,000
4	Central Utility Bldg.,	STR2	Oil	22,900	6,600	20,000
5	Local Elec. Substation1	TR-Chapter 1 (Kicker, Klystron)	Mold	6,600	380	300
6	Central Utility Bldg.,	TR-Chapter2 (LINAC)	Mold	6,600	380	600
7	Local Elec. Substation1	TR-Chapter3 (Modulator)	Mold	6,600	480	600
8	Local Elec. Substation2	TR-Chapter4 (Beamline 1)	Mold	6,600	380	800
9	Local Elec. Substation2	TR-Chapter5 (SR MPS1)	Mold	6,600	380	2,500
10	Local Elec. Substation2	TR-Chapter6 (Control shed rack1)	Mold	6,600	380	800
11	Local Elec. Substation3	TR-Chapter7 (Beamline 2)	Mold	6,600	380	800
12	Local Elec. Substation3	TR-Chapter8 (SR MPS2)	Mold	6,600	380	2,500
13	Local Elec. Substation3	TR-Chapter9 (Control shed rack2)	Mold	6,600	380	800
14	Local Elec. Substation3	TR-Chapter10 (RF1)	Mold	6,600	380	2,000
15	Local Elec. Substation3	TR-Chapter11 (RF2)	Mold	6,600	380	2,000
16	Local Elec. Substation3	TR-Chapter12 (RF3)	Mold	6,600	380	2,000
17	Local Elec. Substation2	TR-Chapter13 (BR MPS)	Mold	6,600	380	2,500
18	Local Elec. Substation2	TR-Day1 (Research Bldg. 1,2)	Mold	6,600	380	1,500
19	Local Elec. Substation2	TR-Day2 (Lightening, Electric appliances)	Mold	6,600	380	1,500
20	Local Elec. Substation2	TR-Day3 (AHU)	Mold	6,600	380	2,800
21	Local Elec. Substation2	TR-Day4 (AHU)	Mold	6,600	380	2,800
22	Local Elec. Substation3	TR-Day5 (Lightening, Electric appliances)	Mold	6,600	380	1,000
23	Central Utility Bldg.,	TR-Day6 (LCW Utility Building)	Mold	6,600	380	2,500
24	Central Utility Bldg.,	TR-Day7 (Central Utility Bldg.,)	Mold	6,600	380	2,500
25	R&D Support Bldg. 1	TR-A (MPS, RF)	Mold	22,900	380	1,500
26	R&D Support Bldg. 1	TR-B (Magnet field measurement)	Mold	22,900	380	300
27	R&D Support Bldg. 1	TR-C (R&D Support)	Mold	22,900	380	2,500
28	Headquarters Bldg.	TR-OF1 (Electric Vehicles)	Mold	22,900	380	500
29	Headquarters Bldg	TR-OF2 (Headquarters Bldg)	Mold	22,900	380	1,000

Local Elec. Substation1 is situated directly beneath the linear accelerator and houses the linear accelerator equipment, including the Klystron, Modulator, and three transformers for the kicker. In Electrical Rooms 2 and 3, transformers for supplying power to the Storage Ring MPS, vacuum devices, and beamline devices are installed. Based on the 12 and 6 o'clock orientations of the accelerator pedestal, the right side is powered from Local Elec. Substation2, while the left side is powered from Local Elec. Substation3.

Transformers for research equipment and general power supply in R&D Support Buildings 1, 2, and 3 are housed in the Local Elec. Substation of R&D Support Building 1, with transformers segregated according to the characteristics of each load. Additionally, one transformer dedicated to electric vehicles and another for the loads of the Administrative Building and Security Management Building will be installed in the Local Elec. Substation of the Administrative Building.

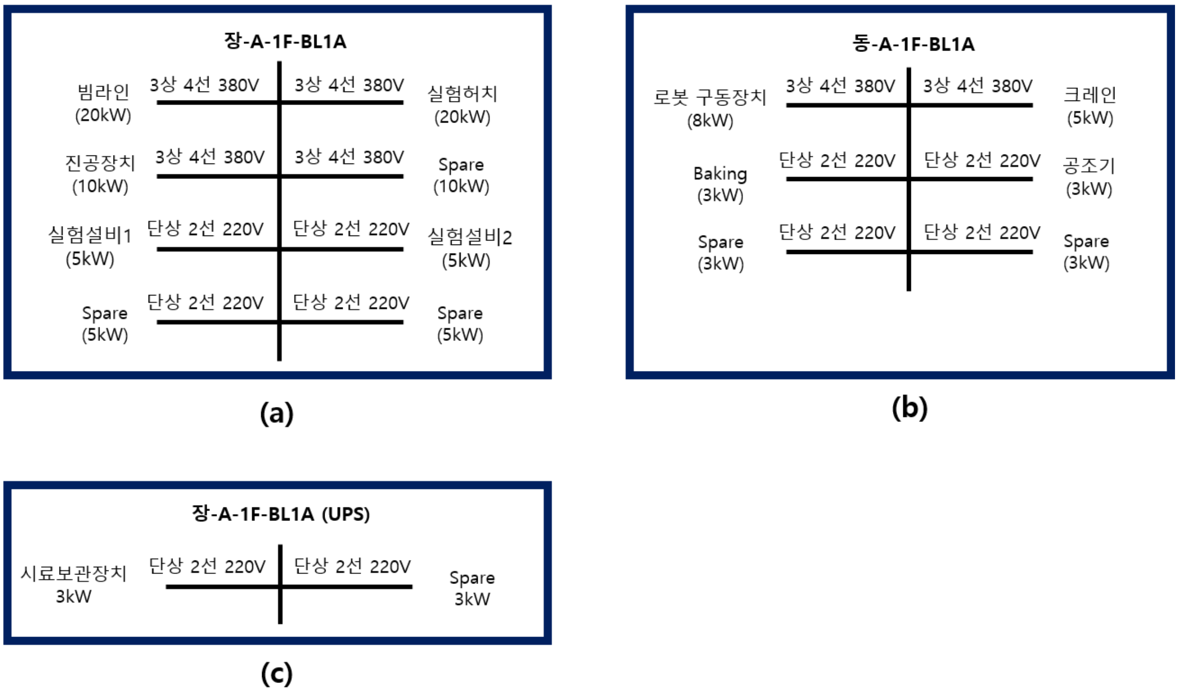
System protection equipment is established to minimize damage to life and property by promptly detecting and isolating faults, overloads, and short circuits. Digital protection relays that enable coordinated protection between upper and lower systems and facilitate data analysis are employed, and a remote monitoring and control system (SCADA) is implemented.

The distribution box for the accelerator and beamline is designed with consideration for the load's location and capacity. Distribution boxes for storage ring and booster devices are installed in each cell of the storage ring along the inner wall of the control shed. The configuration of a general distribution box for a rack is illustrated in (a) of <Figure 5.6.2.1>. For the SR MPS rack, due to its high-power capacity, the distribution box is divided into two sections, as shown in (b) and (c) of <Figure 5.6.2.1>. Moreover, since the MPS does not draw power during maintenance, the power for the vacuum and Front-End distribution boxes inside the tunnel—which operate only during maintenance—is supplied from the distribution box for the SR MPS rack.



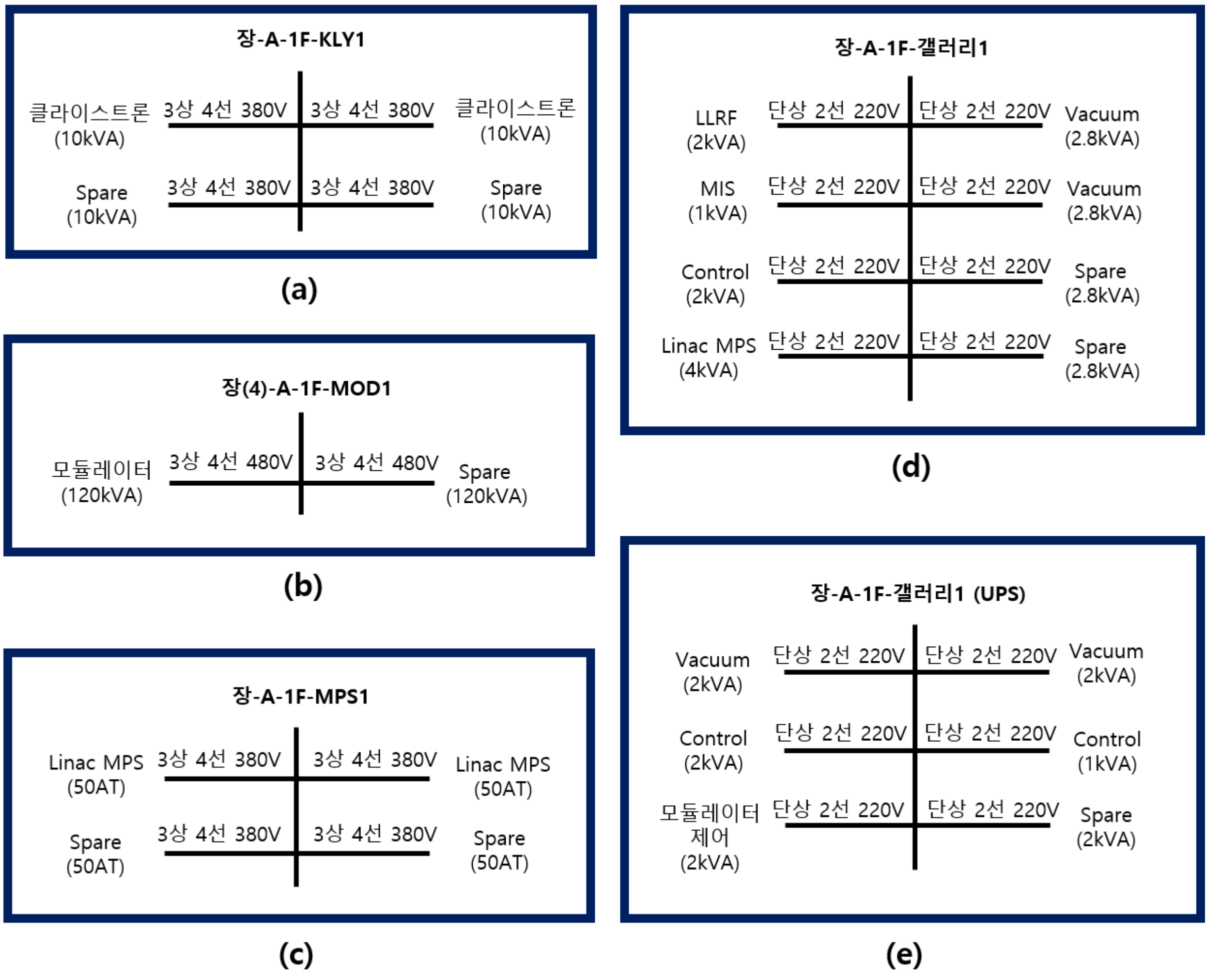
<Figure 5.6.1.2> Distribution box configuration for shed rack of typical cell.

The distribution boxes for beamlines—including the ten beamlines installed in Phase 1—are mounted on the pillars along the experimental hall corridor and are categorized into three types: (a) for equipment, (b) for general power (for HVAC), and (c) for UPS, as illustrated in <Figure 5.6.2.2>.



<Figure 5.6.1.3> Distribution box configuration for beamline of typical cell.

For the Linac, distribution boxes for three M&K (Modulator & Klystron) modules (including one spare module) and an injection distribution box—with an electron gun—are installed in the gallery. The M&K module distribution boxes are composed of separate boxes for the Klystron (a), Modulator (480 V) (b), MPS (c), rack (d), and UPS (e), as illustrated in <Figure 5.6.2.3>, with one distribution box installed for each M&K module in the gallery. Although the rack configuration varies slightly for each module, resulting in minor differences in the distribution box configurations, the overall setup remains similar.



<Figure 5.6.1.4> Distribution box configuration for M&K1 module.

5.6.2 Standby Power Equipment

For emergency power supply—as mandated by the Building Act and Fire Prevention Act—and for 4GSR devices requiring an uninterrupted power supply, a self-power generation facility (emergency generator), UPS, and storage battery systems are installed. The UPS capacity required for stable operation of the 4GSR is summarized in <Table 5.6.2.1>.

The emergency generator activates when commercial power fails, supplying power to the emergency load. The emergency load includes the UPS, firefighting equipment, emergency lighting, elevators, etc. Note that, except for the UPS load, the emergency load is interrupted during the generator start-up and ATS switching period. The emergency generator is installed in the Central Utility Building—with a 1,000 kW unit serving both the Accelerator Building and the Central Utility Building—and in the Main Power Substation—with a 400 kW unit supplying the emergency load for the remaining buildings.

The UPS equipment provides high-quality, constant voltage and constant frequency (CVCF) power to the load. The UPS backup time has been determined to be 15 minutes based on the estimated time required for laboratory permanent staff to initiate manual startup in the event that the emergency generator does not start automatically. To efficiently allocate limited UPS resources, devices connected to the UPS are prioritized based on their criticality. The UPS for the accelerator and beamline is installed in Electrical Rooms 1, 2, and 3 in the infield, ensuring proximity to the load and ease of inspection and maintenance.

<Table 5.6.2.1> UPS capacity by 4GSR device

Building name	Room name	Uses	Device name	UPS (kVA)
R&D Bldg. 1	Biology Lab -1	Beamline common area	-	10
	X-ray Optics Development Lab	Mirror manufacturing technology development and measurement	-	10
	Electrical and Electronic Development Lab	Includes electrical and electronic laboratory assembly room	-	10
R&D Bldg. 1	Data Center	Beamline Data Archiving and Management	-	100
	Biology Lab -2	Beamline common area	-	10
Accelerator Bldg.	SR Tunnel	SR Kicker Power Supply	SR Kicker Power Supply	4
	Control Shed	Booster injection power supply	Booster injection power supply	2
		Booster extraction power supply	Booster extraction power supply	2
		Vacuum Control rack	Vacuum System	56
		Diagnosis/Control Rack	Diagnosis/Control Rack	84
		PSI Rack	PSI	39.6
		RMS	RMS	4
		SSPA for Harmonic cavity, Control rack		14
		SSPA for Harmonic cavity, Control rack		14
	Experimental Hall (Beamline)	1. BioPharma-Bio SAXS	hard x-ray	5
		2. Material Structure Analysis	hard x-ray	5
		3. Soft X-ray Nano-probe	soft x-ray	5
		4. Nano-ARPES	soft x-ray	5
		5. Coherent X-ray Diffraction	hard x-ray	5
		6. CoherentS AXS	hard x-ray	5
		7. Real-time X-ray Absorption Fine	hard x-ray	5
		8. Bio Nano Crystallography	hard x-ray	5
		9. High Energy Microscopy (Long B/L)	hard x-ray	5

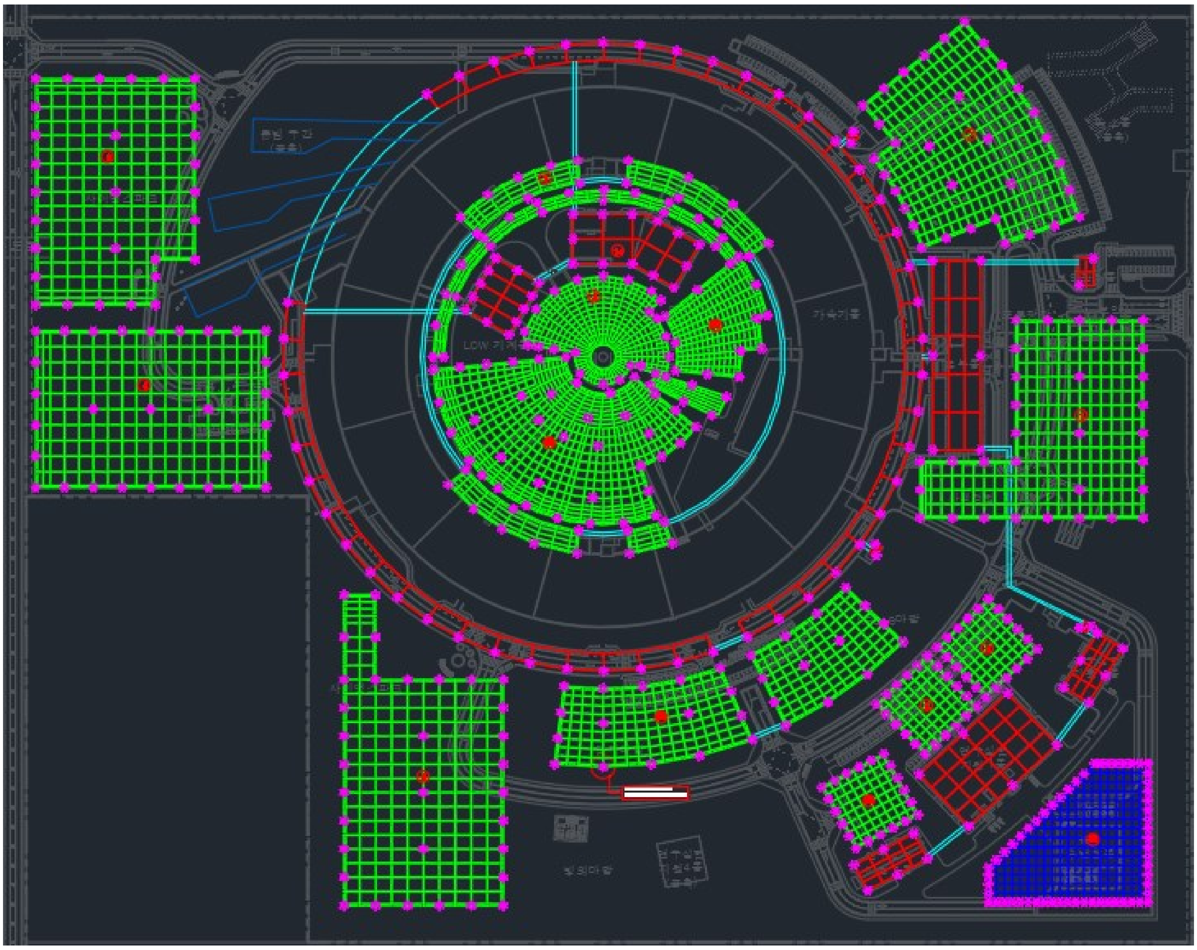
		10. Nano-probe (Long B/L)	hard x-ray	5
	Accelerator Control Room	Accelerator Control Room	TV/Monitor/PC	15
		Control Server	Server	80
			PSI Rack	13.2
Linac	Linac Laser room	Electron Gun	Laser	3
	Klystron Gallery	Linac Equipment	UPS	6
			PSI	2
			RMS	1
			Vacuum	8
			Control Rack	8
	Klystron Assembly Room	Assembly, Test	Modulator Rack	2
RF Bldg.	HPRF Room-2	LLRF, Control Rack	RF UPS Distribution Box 3	18
	RF Control Room	LLRF, Control Rack	RF UPS Distribution Box 2	18
	HPRF Room-1	LLRF, Control Rack	RF UPS Distribution Box 1	18
R&D Support Bldg. 1	RF Test Room	RF Lab	RF Test Room UPS Distribution Box	5
R&D Support Bldg. 2, 3	Radiation Analysis Lab	-	-	10

5.6.3 Lightning protection and grounding equipment

Lightning protection and building grounding adopt an integrated grounding system that consolidates the grounding of electrical equipment, lightning protection devices, and communication equipment. Integrated grounding eliminates potential differences between equipment by forming an equipment, thereby protecting the human body from electric shock. However, when lightning or surges occur, abnormal currents may penetrate along the integrated grounding conductor and damage or disrupt equipment operation. Therefore, the installation of SPD (Surge Protective Device) is essential to safeguard electrical equipment. Lightning protection equipment comprises a grounding device, down conductors, and grounding electrodes, with steel bars or steel structures used in place of traditional down conductors. Additionally, equipment grounding is segregated based on the equipment manager’s requirements.

At the 4GSR construction site, granite is widely distributed, resulting in very high ground resistivity. Consequently, the grounding equipment installation areas were selected based on the grounding requirements for each piece of equipment and future building expansion, as shown in <Figure 5.6.3.1>.

The grounding system employs a mesh electrode and a carbon grounding rod. The carbon grounding rod offers excellent moisture absorption and humidity retention, has a semi-permanent lifespan, and can maintain a low resistance value. A double induction discharge plate is installed to increase the contact area with the ground.



<Figure 5.6.3.1> 4GSR Grounding.

The device grounding must be constructed separately from other groundings and spaced sufficiently in accordance with the device-specific grounding requirements (<Table 5.6.3.1>) to prevent interference with other devices. Since the Kicker, Klystron, Modulator, RF, and MPS use high-voltage pulse power, their grounding grids are segregated. Devices that use low currents, such as lasers and beamlines, have separate grounding grids to avoid interference from other pulse power sources. In addition, the accelerator control server has a dedicated grounding grid to protect it from electrical noise and overvoltage. The resistance value of the device grounding is maintained at 10 Ω. A device grounding terminal box is installed near the device distribution box for convenient access by the load. For safety and device protection, a locking device should be installed in the grounding terminal box, and strict management should be ensured by establishing a management manual.

<Table 5.6.3.1> Device-specific grounding requirements

Building name	Room name	Device	Name	Grounding resistance
LINAC	Linac Laser Room	Gun laser	Laser	NCT, Network Separation, Below 10 Ω
	KLYSTRON Gallery	Facilities for Linear Accelerator Systems	Klystron	Network Separation, Bow 10 Ω
			Modulator	
	KLYSTRON Assembly Room	Device Assembly, Accelerator Testing, Oil Replacement	Klystron	
			Modulator	
Accelerator Bldg.	SR Kicker Room	SR kicker	SR kicker power supply	
	Control shed	Booster injection	Booster injection power supply	
		Booster extraction	Booster extraction power supply	
		SR MPS rack	SR MPS	Network Separation, Below 100 Ω
		BR MPS rack	BR MPS	
	Experimental Hall (Beamline)	Experimental Hall	First Quadrant	Network Separation, Below 10 Ω
			Second Quadrant	
			Third Quadrant	
			Fourth Quadrant	
	Accelerator Control Room	Server Room (Accelerator Control Server)	Server	
RF Bldg.	HPRF Room 1	LLRF, 16 Control Racks + 2 Spares	RF UPS Distribution Box 1	
	RF Control Room	General Load	RF UPS Distribution Box 2	

		LLRF, 16 Control Racks + 2 Spares	RF UPS Distribution Box 2	
	HPRF ROOM 2	LLRF, 16 Control Racks + 2 Spares	RF UPS Distribution Box 3	
		Storage Ring CAV SSPA from 03 to 10 (8 Units)	SSPA 150 kW	
		Storage Ring CAV Load + Circ. from 03 to 10 (8 Units)	Load + Circulator 180 kW	
		General Load	RF UPS Distribution Box 1	
R&D Support Bldg. 1	RF Test Room	RF Laboratory (LLRF Control Rack)	RF Test Room UPS Distribution Box	
	MPS Lab	MPS Laboratory (Electromagnet Laboratory)	MPS	
Magnetic Field Measurement Room	Magnetic field measurement room	MPS Power Supply	MPS	
		Electromagnet Measurement and Storage	Magnetic Field Measurement	