4 Conventional Facilities

4.1 Introduction to conventional facilities

The upgrade of CESR to ERL capability requires the addition of new buildings and infrastructure in and around the existing Wilson Laboratory complex. The ERL upgrade keeps the ERL effort on the central portion of the Cornell campus where it will remain as an integrated campus research activity easily accessible to students, staff, and faculty. As Wilson laboratory is situated in the Cascadilla Creek and Cascadilla Meadows area, it has additional design requirements beyond just providing a functional set of buildings for he ERL activity. It must also satisfy campus master and natural areas plans, as well as state and town building and traffic codes. The appropriate members of the Cornell community have been included in the development plans since the inception of the design work. The development team, consisting of the external ARUP design group and local Cornell planners, has incorporated significant measures to protect the creek itself and the wetlands to the west of Wilson to hide a visibly industrial cryoplant building underground for visual and sound-deadening purposes, and to make the recessed new buildings a harmonious part of the earth landscape with green roofs and carefully landscaped outdoor courtyards.

With over 250,000 ft^2 of new expansion space, the utility needs of the building structures have increased. New 13.2 kV electric power substations will be incorporated in the cryoplant with satellite substations in the ERL laboratory. Substantial electric power is needed to operate the compressors that liquefy helium gas in a closed-circuit refrigeration loop. The cryogenic liquid helium subsequently is distributed downward into the tunnel underneath to cool the superconducting Linacs that make up the heart of the ERL accelerator. We are investigating the possibility that waste heat from the water-cooled compressors would be available for heating the ERL building as well as nearby campus structures. In addition, campus chilled water will be needed for the increased heating, ventilation, and air-conditioning demands of new structures, such as the ERL building. The specifics of these areas are further discussed in subsequent sections on Geographical Layout, Conventional Construction, Utilities and Cryogenic Systems.

Funds from the state of New York and from Cornell were essential to complete the work of this chapter because NSF support could not be used for this and other site specific work.

4.2 Geographic Layout

4.2.1 Introduction to the Wilson Laboratory site

Accelerator physics and x-ray science at Wilson Laboratory are intimately connected. The mission of the Cornell Laboratory for Accelerator-based ScienceS and Education (CLASSE) is to conduct research on accelerators for Elementary Particle Physics (EPP) and synchrotron x-ray science, to operate accelerators for x-ray science, and to educate the future workforce for this field. CLASSE currently operates the accelerator complex on the central Ithaca campus (Fig. 4.2.1), which has provided data for the CLEO-c HEP experiment (a collaboration of 150 scientists from 25 institutions whose mission is now completed) and continues to provide x-rays for CHESS, one of only five U.S. national hard x-ray synchrotron facilities. CLASSE is also heavily involved in accelerator physics research and the development of a high brightness Energy Recovery Linac facility for future x-ray applications. CLASSE results from a very productive, half-century-long collaboration between accelerator physicists, elementary particle physicists, and x-ray based structural scientists. In 1952, Cornell physicists who were building an electron synchrotron for EPP purposes collaborated with condensed matter physicists to build the world's first synchrotron radiation beamline to characterize and apply the radiation to the study of matter. Over the next three decades, a succession of larger and more capable accelerators were built, each in turn contributing to both EPP and synchrotron science. In the mid-1960s, the present Wilson Lab site was constructed to house a large (0.8 km circumference) synchrotron and the associated experimental facilities. In the mid-1970's, the NSF Physics Division (PHY) funded the addition of the Cornell Electron Storage Ring (CESR) for EPP, and the NSF Division of Materials Research (DMR) funded a national synchrotron radiation facility (CHESS) using the radiation produced by CESR. CESR and CHESS commenced operations in 1979 and are, with countinuous upgrading, still being used today. They have each made numerous world-class contributions to EPP, accelerator, and synchrotron x-ray sciences.

The resulting infrastructure of necessary technical skills (accelerator physics, vacuum, electronics, computer, safety, mechanical, etc.), as well as an administrative organization capable of dealing with large-scale national user facilities matches well with the requirements of a major particle accelerator facility. This infrastructure includes the additional resources required for specific EPP and x-ray science. This infrastructure, which has been working effectively at Wilson Lab for decades, was reorganized and renamed CLASSE in 2006.

CLASSE is chartered as a Cornell University Center, which means that it is an interdisciplinary organization of faculty and staff to facilitate and promote research and education in the branches of science concerned with the development and uses of accelerators. Faculty members represent many Cornell departments, including physics, chemistry and chemical biology, applied and engineering physics, materials science and engineering, and molecular medicine, to facilitate postdoctoral and student (undergraduate, graduate) involvement in education, training, and research, and to involve the intellectual resources of a wider university community. The CLASSE directorate is a mixture of faculty and senior professionals, whose purpose is to integrate research and education activities (e.g., x-ray science, EPP) with technical functions requiring full-time operations staff.

Figure 4.2.1: The Cornell Electron Storage Ring (CESR) from the air showing its location on the central Cornell campus in Ithaca, New York. The Newman Laboratory for SRF studies, the Physics Department, the School for Applied and Engineering Physics, the Cornell Nanofabrication Facility and Biotechnology buildings are all located within a 10-minute walk of the CESR accelerator inside Wilson Laboratory. The white circle outlines the CESR ring approximately 50 feet underneath the athletic track located topside.

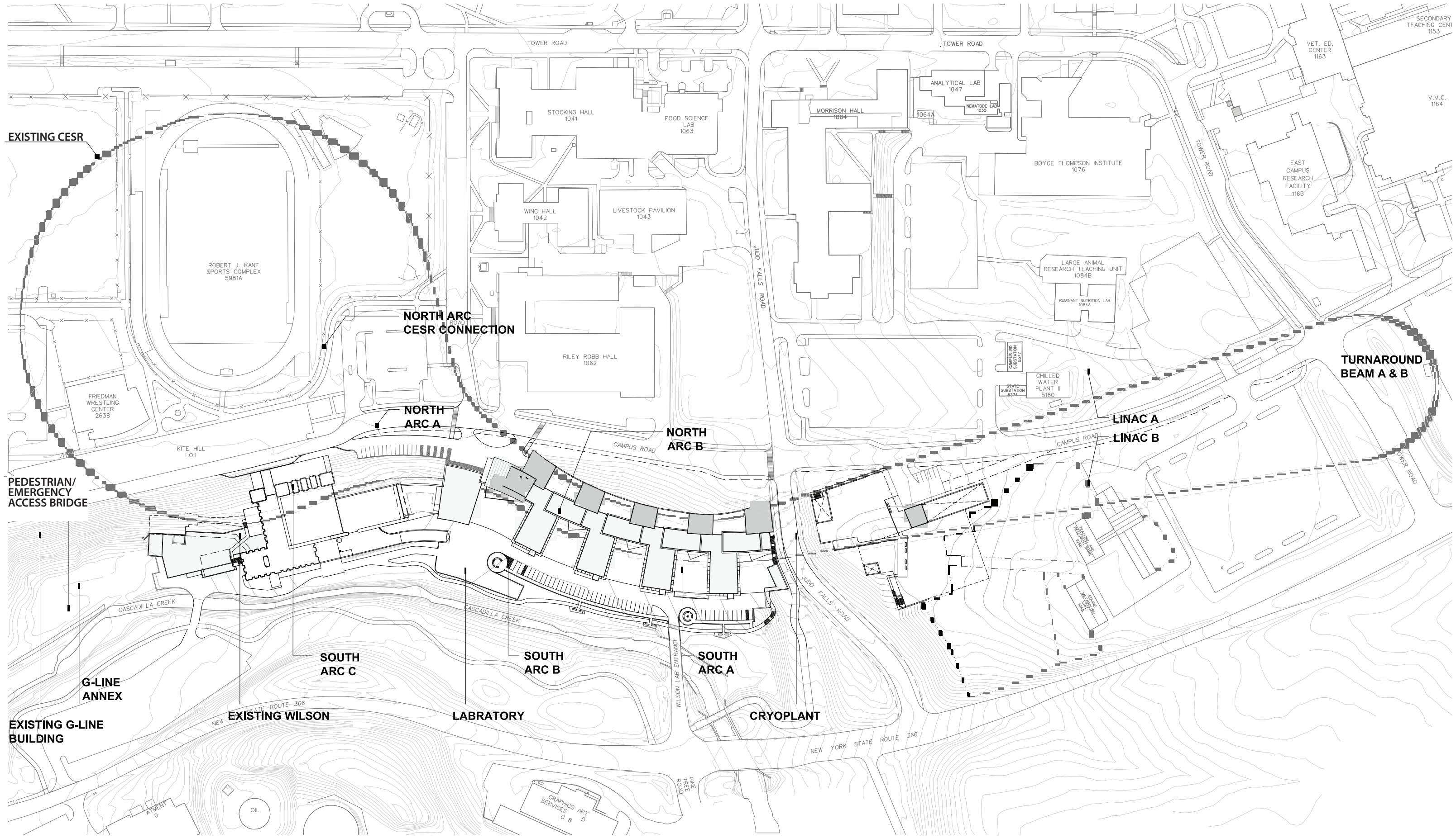


Figure 4.2.2: Proposed development overview (from Fig. 3.2 in [1]). The plan is to add a new ERL laboratory building of 238,000 gross square feet (gsf) with the lower floor at the 827' level to accommodate up to 18 new x-ray undulator beamlines. A 1 km bored tunnel will be added in which two new sections of SC Linacs will be positioned with the east turn-around arc. To the west of the ERL lab, a short north arc tunnel will be added. The existing CESR ring/tunnel at the 827' level will serve as the west turn-around arc and the present Wilson laboratory will continue to provide infrastructure and services. A cryoplant building with a floor at an elevation of 870' will be buried underground as 'landscape/earth sculpture' to minimize visual impact and noise of the highly industrial nature of a cryoplant/cooling coil complex. Finally, a new footbridge will be added across Cascadilla Creek near the west addition for nearby parking in the existing Oxley parking lot.

4.2.2 Physical infrastructure

Present available space

An important aspect of the ERL facility is that it is readily accessible to both its nationally-based future user community and Cornell faculty, staff and students. Because of its prime location on campus, it is fully integrated into the academic life of the University. Existing facilities include: Wilson Laboratory: 71,150 sq.ft; Wilson Annex, 8,890 sq.ft, just across 366 NY state highway; Wilson Lab Modular Space, adjacent to Wilson, 8,880 sq.ft; Several facilities also have net assigned square feet: Newman Laboratory, two connected buildings about half a mile from Wilson, 34,000 sq.ft; and a rented warehouse space (JBC), 14,400 sq.ft. The present value of the Wilson Laboratory complex and infrastructure is estimated at several hundred million dollars.

The supported research program has available to it the full facilities of the Wilson/Newman Laboratory complex at Cornell University. CHESS, the NSF-supported National User Facility, is part of this complex. The Wilson/Newman Laboratory complex is a set of fully self-contained, major accelerator physics, and synchrotron radiation national facilities, and includes the full complement of metal, electronic, vacuum, chemical, and computer shops and stockrooms. Additional shop facilities of practically any type required are available as part of Cornell's research facilities. These include the Cornell National Nanofabrication Facility and materials characterization facilities at the Cornell Center for Materials Research.

An additional 3000 square feet of research space in Clark Hall houses the Cornell x-ray detector development group, under the direction of Prof. Sol Gruner. This capability includes: a full set of the computer tools to perform Pixel Array Detector (PAD) integrated circuit design, simulation and testing; equipment required to test custom analog and digital detector PAD integrated circuits; clean laminar flow hoods; dark boxes equipped for PAD diode testing; and x-ray generators and beamline equipment for x-ray testing and calibration of detectors. Most importantly, the laboratory is staffed by professional personnel highly experienced in all aspects of PAD design, fabrication, and assembly.

Conceptual design study to expand the Wilson complex for ERL capability

A conceptual design study has been completed by ARUP, a global consulting, engineering, and planning firm with 86 offices worldwide with a reputation for quality and innovation in the field of sustainable planning, consulting, and design. These plans present a definition design and cost estimate for the civil engineering infrastructure of the Energy Recovery Linear Accelerator (ERL) light source extension of the CESR facility to be proposed by Cornell University. The layout overview is shown in Fig. 4.2.2. The design represents a practical concept for meeting the facility needs.

Key requirements of the expanded facility are:

- Provision of an east experiment hall with low vibration floor to accommodate up to 14 new x-ray beamlines based on insertion devices in the same horizontal plane as the existing storage ring

- Provision of associated laboratory, workshop, office, and ancillary space to support the experiment hall

- Provision of a west addition (G-line Annex) to accommodate one new x-ray beamline and also expansion space for the existing G-line building
- Construction of one kilometer of new tunnel to house the ERL Linac and turn-around arcs
- Accommodation of the cryogenic infrastructure to provide and distribute liquid helium to the twin Linacs and their associated equipment
- Provision for utility, servicing, parking, and access in support of the program described above
- Integration of the new facility with the Cornell campus master plan (see Fig. 4.2.3) and its environmental and sustainability objectives
- Integration of the new facility with the planned reuse of the Wilson laboratory building, CESR tunnel, and accelerator and utility infrastructure
- Completion of all major civil construction within a five-year time period

The report presents a concept design for conventional construction to support the ERL facility and is composed of three volumes:

[1] ARUP Volume 1: Technical Report, May 2010, Issue 4

[2] ARUP Volume 2: Drawings, May 2010, Issue 4

[3] ARUP Volume 3: Cost Plan and Schedule, May 2010, Issue 3

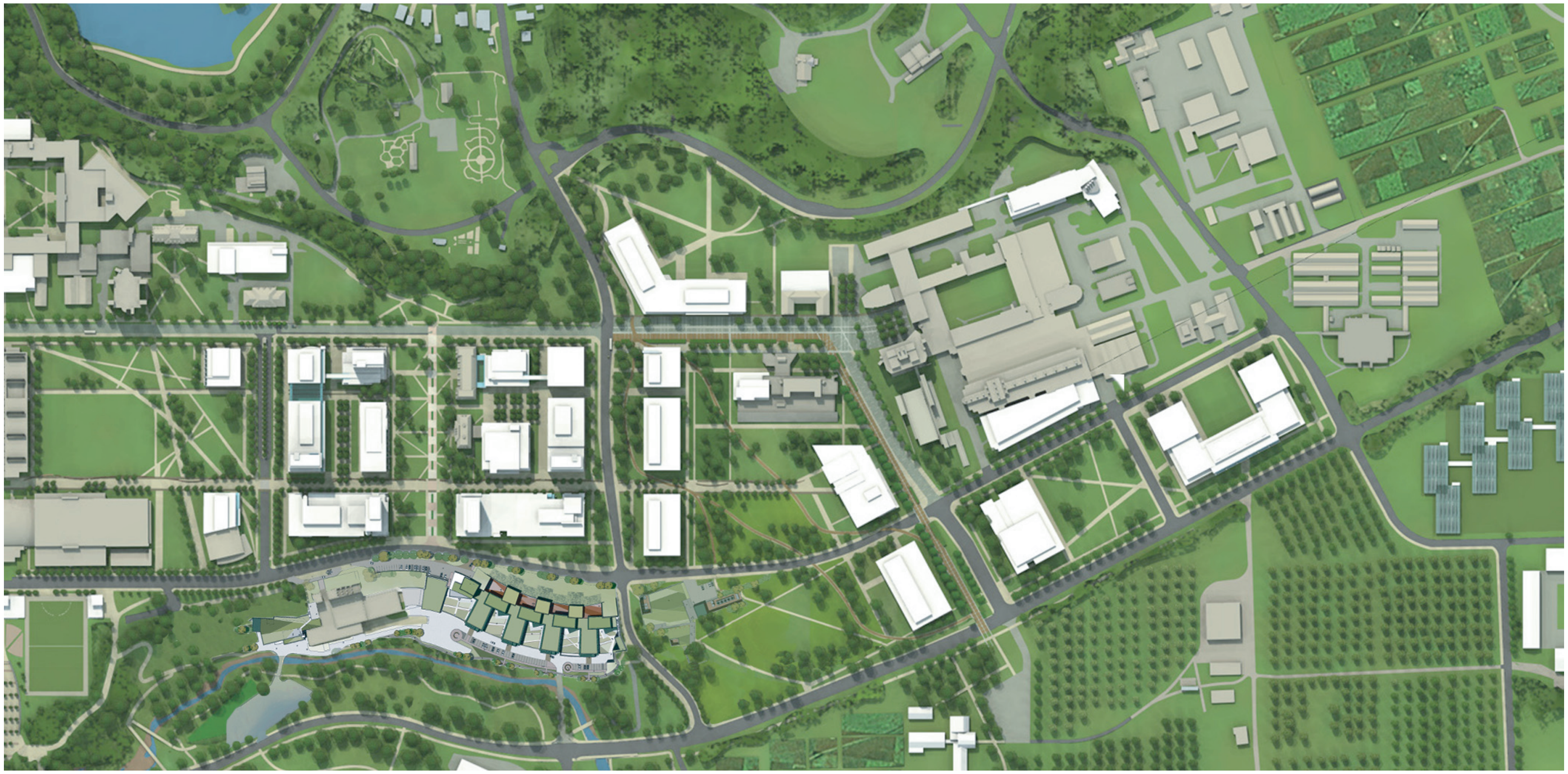


Figure 4.2.3: Cornell Master Plan (from Fig. 3.9 in [1]) showing a projected visual view of the campus over the next 10 to 25 years including the ERL building with its patches of green roof and underground cryoplant attached to Wilson Laboratory. Key issues that are crucial to success of the design are: 1) minimizing the visual impact of the ERL building and support structures to this entrance to the Cornell campus; 2) maintaining the structural, ecological, and visual integrity of the Cascadilla Creek and gorge area; 3) integrating landscape and infrastructure design with habitat restoration, storm water management, circulation, and recreation; and 4) accommodating the service and access requirements of staff and visitors to the ERL facility.

4.2.3 Facility layout considerations

The proposed ERL project has three main elements: (i) new additions to the east and west of the existing Wilson Laboratory, (ii) a Tunnel Loop Extension - an extension loop to the east of the existing underground CESR tunnel, and (iii) a Cryogenics Plant east of Judd Falls Road, which will be mostly below grade (see Fig. 4.2.2). The main laboratory building occupies what is now an empty hillside and parking spaces between the Wilson Laboratory and Judd Falls Road. The proposed ERL project site is bounded to the north by Campus Road, to the east by the College of Agriculture and Life Sciences (CALS) teaching and research barns (east of Judd Falls Road), and to the south and west by Cascadilla creek and the associated Cascadilla Meadows Natural Area.

The proposed site design reflects three major influences: the new electron beam geometry, the topographic constraints of steep slopes and Cascadilla Creek, and the campus infrastructure of roads and open space. The ERL tunnel location avoids nearly all existing campus structures overhead, minimizing impact and perceived risk of damage from ground motion during tunneling. The site and landscape design for the ERL facility takes into account all existing conditions and is consistent with the development and landscape recommendations of the 2008 Cornell Master Plan.

East and west additions and pedestrian bridge

The fingered roof layout above the large East Addition provides space just above the experimental floor with ample natural lighting and outside access. Adjacent parking areas permit ready access to the experimental floor, laboratory, and office spaces.

The building design takes advantage of the natural contours of the site located in the Cascadilla meadows. A concept of a partially submerged 'earth sculpture' has been presented that minimizes the impact of a large footprint on the surrounding campus and preserves key viewing corridors and access routes identified in the Cornell Campus Master plan. The ERL building orients faces the southern part of the Cascadilla creek gorge, with its backside carved into the hillside (see Fig. 4.2.4). The ERL building has been designed to maximize daylight and Cascadilla Creek views from the office areas. The proposed external construction materials respond to the natural environment of the surrounding creek, and are made of slate at the lower level and semi-transparent glass/metal wall sections on the upper levels (see Fig. 4.2.5).

The East Addition will have an entrance on Campus Road to the east of the existing Wilson Laboratory, but otherwise will present a limited visual presence on Campus Road. This entrance structure was sited to frame existing views south toward Cascadilla Creek from Wing Drive and Campus Road. The majority of the East Addition will be below the level of Campus Road, with the series of green roofs and landscaped courtyards stepping down the slope. Street lights will be restored and groupings of street trees will be planted along the south side of Campus Road.

The main user entrance to the ERL facility will remain at the lower level via the existing entry drive and the proposed pedestrian bridge from NY State Route 366. Much of the building will be set into the slope, with the most visible elements being a series of open laboratory and office modules interspersed with landscaped courtyards and green roofs that emerge from the low masonry base of the building and the existing slope. Floor areas for various uses are given

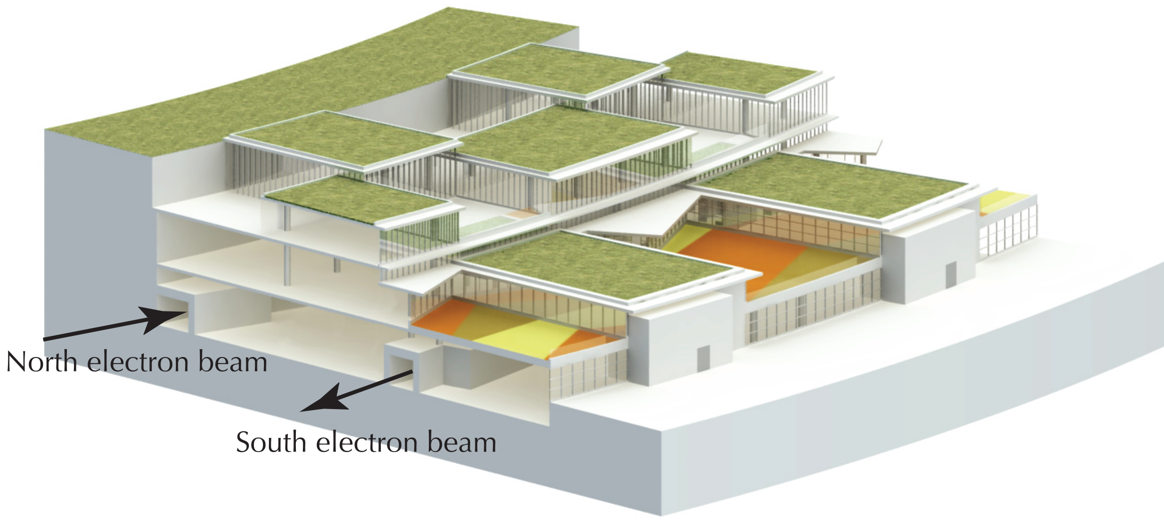


Figure 4.2.4: Cut-away showing how the ERL building becomes a landscape (from Fig. 3.19 in [1]). The north wall of thefour-story building is a retaining wall to hold back the hillside just below the nearby Riley-Robb building. The first floor at the 827' level passes the electron beams through undulators (not shown) inside the shielded vaults in the directions shown for the south and north sets of x-ray beamlines. The second floor at the 847' level contains offices in the front, conference rooms, and laboratory rooms adjacent to the back retention wall. The third floor at the 865' level contains more offices as well as heating and air conditioning equipment. The fourth floor at the 880' level (not depicted in this sketch) provides a lobby and loading area from the Kite Hill entrance to the new ERL building from the upper parking lot. The green 'living roof' structures shown are planted with sedum growing in soil placed over a double-waterproofed membrane.

in Tab. 4.2.1. Emphasis is on space to support scientific users of the facility. Technical support for the accelerator will be primarily in the existing Wilson Laboratory building.

The stone masonry base and the landscaped courtyards and green roofs that are seen from the south, visually tie the building to the surrounding landscape, and define outdoor areas for building users. Each courtyard will be treated differently with a variety of planting and paving materials and patterns. The southern (lower) courtyards provide seating areas and gardens for the office staff. Passive and active uses are envisioned for these spaces with each courtyard providing a different experience to help promote connections between building users. The northern (upper) courtyards will function as access to the mechanical rooms, so most of the surface will be paved with gravel and various pavers.

The primary user and service access to the ERL facility will remain at the lower level. A single row of approximately 40 parking spaces is proposed south of the Wilson Addition with an access drive between the building and the parking. Bicycles and pedestrians would also use the existing drive to access the site, with bicycle parking adjacent to each of the four

Figure 4.2.5: South facade of the existing Wilson Laboratory (brown brick, left) and the proposed green/gray ERL building (on right) (from Fig. 3.62 in [1]).

Table 4.2.1: Floor areas for various uses.

Use	Area (ft^2)
Experiment hall	57,727
Laboratories	16,898
Offices (40% closed, 60% open)	11,095
Conference/multi-purpose	4,794
Shop areas	5,669
Mechanical/storage	15,158
Circulation/corridor/lounge	27,597
Other (kitchenettes, toilet, lobby)	3,973

entrances to the building. Trucks accessing the Wilson Lab loading ramp, as well as emergency and service vehicles, will drive through the parking lot, then use the turn-around to back into the ramp.

Wherever possible, the setback between the creek and built structures has been increased to allow for a larger planted buffer than currently exists. Existing vegetation along the creek will not be disturbed, except to remove selected invasive species. The closest structure to the creek will be the pedestrian pathway, which follows existing contours to minimize disturbance and utilizes porous paving to minimize runoff. Areas between the pathway and Cascadilla Creek that are currently developed will be reclaimed as part of a natural landscape by removing any structures and undesirable fill material, and replaced with planting soil and seeding of a native seed mix. Native tree species will also be planted between Cascadilla Creek and the path to add to the existing tree canopy along the creek and provide shade.

Emergency vehicles will have the ability to continue across a pedestrian bridge (see Fig. 4.2.2) to access Dryden Road via the Oxley parking lot. While primarily designed for pedestrian use, the bridge will be designed to allow fire department access to the West Addition. The proposed pedestrian footbridge across Cascadilla Creek will connect the ERL Laboratory to the Oxley (T1) parking lot and the pedestrian trail through the Cascadilla Meadows Natural Area south of the creek. The bridge will allow personnel parking south of the creek in the Oxley lot to access the building and enhance the infrastructure of trails and walks on campus.

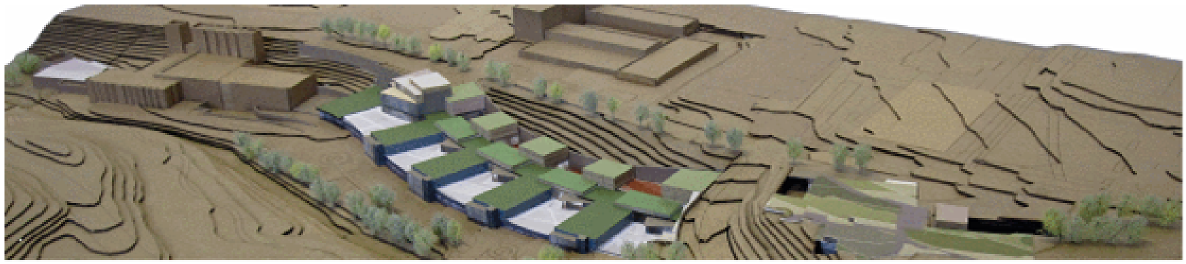


Figure 4.2.6: Model shot of aerial layout. The existing Wilson laboratory is on the left and the new experimental hall to the east of Wilson laboratory is in the center (shown with green roofs). The underground cryoplant is to the right.

Tunnel loop extension

The tunnel structure continues under Judd Falls Road, below the existing topography and roadway system. The proposed location and layout for the tunnel loop extension from the existing Wilson Laboratory, is shown in Fig. 4.2.2. The loop expansion to the tunnel will be located 20 to 85 feet underground. The tunnel loop will be imperceptible at the surface level. All street, sidewalk, lawn, landscape and other above ground areas disturbed by construction will be restored to their original condition after construction.

Cryoplant addition

The Cryogenics Plant will be located east of Judd Falls Road and south of Campus Road. The land is currently used as pasture for the CALS Teaching and Research Barns, and provides views to the hills and surrounding landscape to the south. The cryoplant building outline is shown to the right (East) of Judd Falls Road in Fig. 4.2.2 and in Fig. 4.2.6. Judd Falls Road separates the east addition from the cryogenics plant with the tunnel extension running far beneath it.

Over 90 % of the Cryogenic Plant will be underground. The visible elements above ground include a one-story entry pavilion with a short service driveway, and up to five parking spaces off Campus Road. A secondary access route connecting the parking lot to Campus Road is designed to accommodate the large trucks that infrequently need to make deliveries to the cryogenics plant. The majority of the cryogenics plant site will remain as, or be restored, to meadow, including those portions of green roof over the underground structure. This will maintain views over the top of the building to the surrounding landscape.

The building is designed to facilitate operation and maintenance, including replacement of major components, of cryogenic equipment. In addition to being the central distribution point for electrical power, the cryoplant building houses the high voltage DC power supplies for the injector klystrons.

Site vibrations, roadways, and parking over labs

Site vibration tests indicate that the vibration influence of Campus Road traffic is negligible on the floor of the Cornell Electron Storage Ring (CESR) tunnel. This is believed to be due to the substantial soil depth (of about $\sim 50\,\mathrm{ft}$) between the roadway and tunnel. Similarly, it is expected that the location where Judd Falls Road is proposed to pass above the east laboratory building will be acceptable given similar soil depth conditions between the roadway and east experimental floor area. For a CESR tunnel floor plot of amplitude vs. frequency, see Fig. 2.10.15. The spectra taken on the tunnel floor, on quadrupole frames, and on CESR beampipes will form the basis for determining what further isolation of sensitive machine components is needed to meet the stringent ERL beam stability requirements. The main east experimental floor is expected to have an amplitude vs. frequency response similar to that in the present CESR tunnel.

Environmental noise criteria

The criteria for maximum allowable outdoor noise emissions from the new facility will not exceed 5 dBA above ambient noise levels at adjacent roads and walkways. This applies to the cryoplant and all other mechanical services for the new facility. A separate study [4] has been conducted to evaluate the existing ambient levels and model the anticipated building impact on the surrounding environment. The designed underground cryoplant can meet all the requirements for no more than a 5 dB increase in the ambient noise level.

References

[1] ARUP. *Energy Recovery Project Definition Design, Volume I Report.* Technical report (2010).

[2] ARUP. *Energy Recovery Linac Project Definition Design, Volume II Drawings*. Technical report (2010).

[3] ARUP. *Energy Recovery Linac Project Definition Design, Volume III - Cost plan and schedule*. Technical report (2010).

[4] Epsilon Associates, Inc. *Sound Level Impact Assessment Report*. Technical report (2008).

4.3 Conventional construction

4.3.1 Overview

Conventional construction will provide the building and tunnel infrastructure and utilities to install, operate, and carry out the experimental program of the Cornell ERL. The conventional facilities must provide a stable foundation to meet the exacting demands of the ERL performance goals, and provide a safe working environment for users and operations staff. The conventional construction must support the overall goals of the ERL facility in an economical, environmentally sound, and harmonious manner.

Wilson laboratory and CESR accelerator components will be largely used for the ERL, providing office, laboratory, and shop space, a substantial part of the utilities, and a large-radius turn around for ERL beams at the 5 GeV energy.

A definition design and cost estimate for the conventional facilities and tunnel is presented in a report from ARUP an international design and consulting firm specializing in state-of-art and unusual projects [1–3]. The highlights of this report are presented here.

4.3.2 Facility requirements

The design represents a practical concept for the following needs of the Cornell ERL:

- Provision of an experiment hall with low-vibration floor to accommodate up to 12 new x-ray beamlines in the same horizontal plane as the existing storage ring
- Provision of an annex building west of Wilson Lab to accommodate an additional x-ray beam line in the same horizontal plane as the existing storage ring
- Provision of associated laboratory, workshop, office, and ancillary space to support the experiment hall
- Construction of approximately 968 m of new tunnel to house the superconducting Linacs
- Accommodation of the cryogenic infrastructure to provide and distribute superfluid liquid helium to the Linacs and their associated equipment
- Provision of appropriate utility, servicing, parking and access to support the whole program described above
- Integration of the new facility into the Cornell-campus master plan, and implementation of local environmental and sustainability requirements
- Integration of the new facility with the planned reuse of the Wilson-laboratory building, CESR tunnel, accelerator and utility infrastructure
- Completion of all major civil construction within a five year time period

The main laboratory building accommodates an experimental hall with 12 beam lines, offices, preparation laboratories, shop space, conference rooms, break areas, lavatories, and accelerator infrastructure. The building is designed to minimize visual impact, fitting snuggly into what is

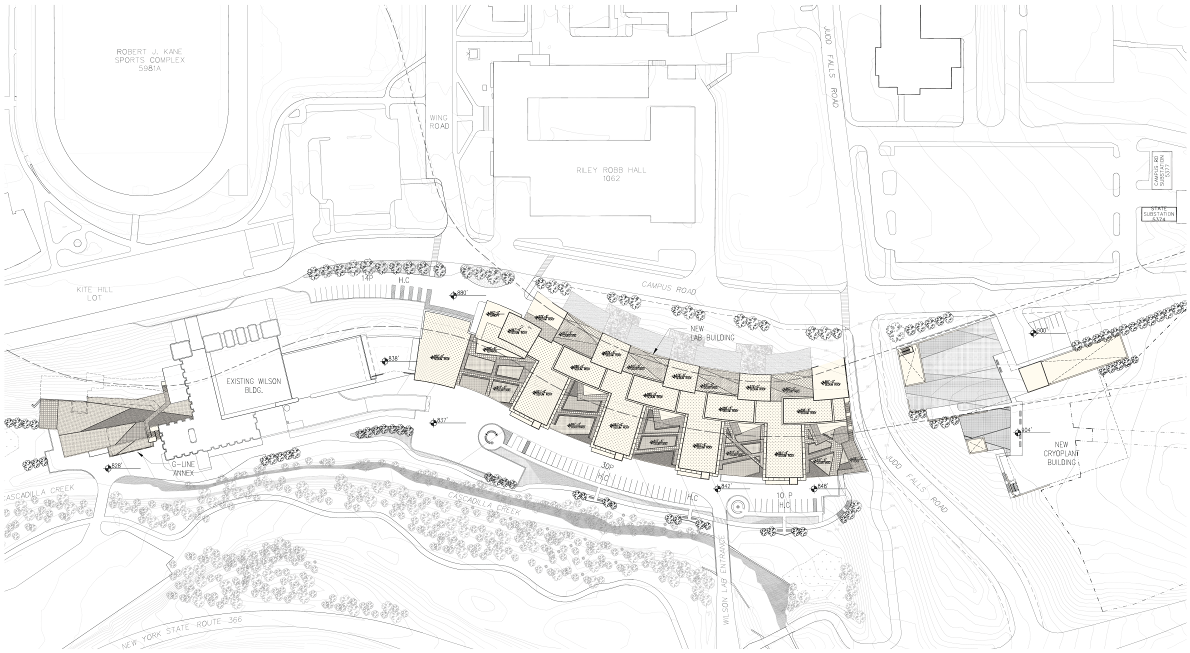


Figure 4.3.1: Green roof plan for west and east additions and the cryoplant

now a hillside. The building is targeted to achieve a Leadership in Energy and Environmental Design (LEED) silver rating and initial assessments demonstrate that this should be achievable as the design progresses. A separate, mostly underground, structure houses the cryogenic equipment to produce and deliver 2 helium to the RF cavity cryomodules in the tunnel. Vibration and noise issues were addressed early in the design. This building also accommodates a new 13.2 kV electric supply and distribution center as well as HVAC equipment for the cryo building and tunnel.

4.3.3 Major components

The major components of the conventional construction are described in the following sections.

Main east laboratory building

The entire lower level is devoted to equipment and the personnel monitoring experimental work, with the upper level devoted to laboratory and office uses. The length and number of x-ray beamlines leads to a ‘grouping’ of lower-level experimental space with upper-level office and lab support, creating a ‘modular’ grouping. The lines each have an associated area of office and lab/support space directly above. Each of these modules has associated infrastructure of electric/ mechanical/toilet core areas as well as lounge and kitchenette/vending areas for informal social and academic interaction.

These areas are located at stairwell locations connecting to both the lower levels and upper levels, and are located at exterior landscaped roof courtyards to maximize exposure to natural light into the lower and upper-level offices and labs. These accessible courtyards would be a

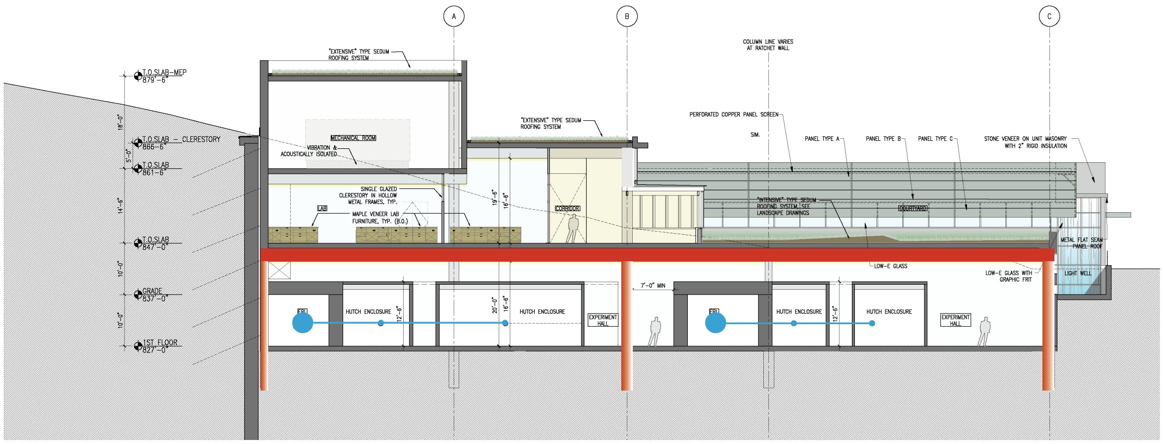


Figure 4.3.2: Cross section of the east addition building with twin Linacs and x-ray beamlines on the bottom floor; laboratory, office, and courtyard are on the first floor; and the mechanical room is on the third floor. The building is constructed next to a secant pile holding the hillside in place.

combination of outdoor use areas and low maintenance landscaped elements; a new 'green' roof and building for this natural site, Fig. 4.3.1. A conference center anchors these modules at its western end, closer to the existing Wilson Laboratory building, creating a new entry to the complex at the upper level at Campus Road.

The steep site is also a functional driver of the new building design. A large amount of the soil from the existing 'hill' must be excavated and retained to create the major floor level at 827 feet. The average grade of Campus Road is at 880 feet, over a 50' height differential of soil to be retained. The need to hold the hill back and to hold the road in place suggested a system of 'building blocks' stacked against this hill together with a massive concrete structural system to limit any surrounding vibration as shown in Fig. 4.3.2

The main experimental hall floor plans are shown in Fig. 4.3.3 and Fig. 4.3.4 . The building accommodates 12 primary beam lines, 7 using the beam directly from Linac B, and 5 using the beam returning from CESR. The floor elevation is 827 ft., 10 feet below the parking lot level with access by stairs, elevators, and a loading dock with a ramp and a 20 ton trolley hoist. Hutches accommodate a variety of experiments.

The experimental floor is a slab 12" thick slab on prepared glacial till. The columns that support the floors above are isolated from the slab to prevent transmission of vibrations from equipment and activities on floors above.

The ceiling above is a one–way, truss-supported concrete slab. Concrete columns support this structure and those above. The columns are isolated from the surrounding floor slab to reduce transmission of vibrations to experimental equipment.

The second level includes offices, laboratories, shop areas, and utilities. The laser room and injector klystron gallery occupy the northeast (upper right) corner of this floor. A minimum 7–foot–wide access is provided from the eastern-most courtyard to the klystron gallery for equipment installation. A multipurpose conference room is at the western end. The third level houses utility areas and a large conference room with an adjacent vestibule that has a

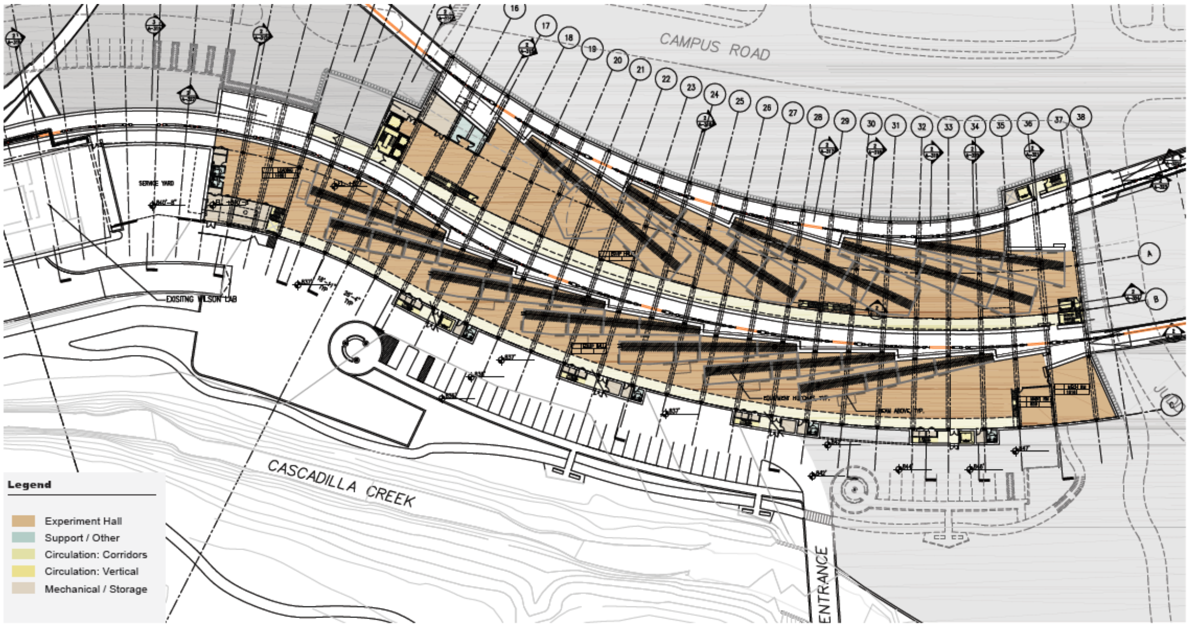


Figure 4.3.3: East building addition at 827´ elevation, showing twin Linacs and 12 x-ray beam-line capability.

capacity for 150 people.

Cryoplant building

The cryoplant is housed in a single level underground structure that contains compressors, expansion engines, valve boxes, cooling towers, tunnel HVAC equipment, primary electrical distribution, and injector klystron high-voltage power supplies. The 24–foot ceiling and pads open to the surface and provide access for equipment maintenance as seen in Fig. 4.3.5).

G line annex

On the far western side of Wilson lab, the G Line Annex will provide experimental and support space for a long beam line. The 13,863–square–foot facility will provide space for experiments, offices, labs, bathrooms, and storage.

4.3.4 Geotechnical engineering

The new facility will be built next to a steep hillside comparable to, but on a larger scale than the G–line construction that took place in 1999, when CHESS was extended by this extra x-ray line. The building will require permanent anchored retaining walls to retain the soil along the north and east sides. A large part of the wall will be between 40 and 60 ft high, with a maximum height of approximately 65 ft at the northeast corner. Slope stabilization will be accomplished by installing a permanent secant pile wall restrained by permanent anchored tiebacks to support the northern excavation line at the eastern end of the building. Actual

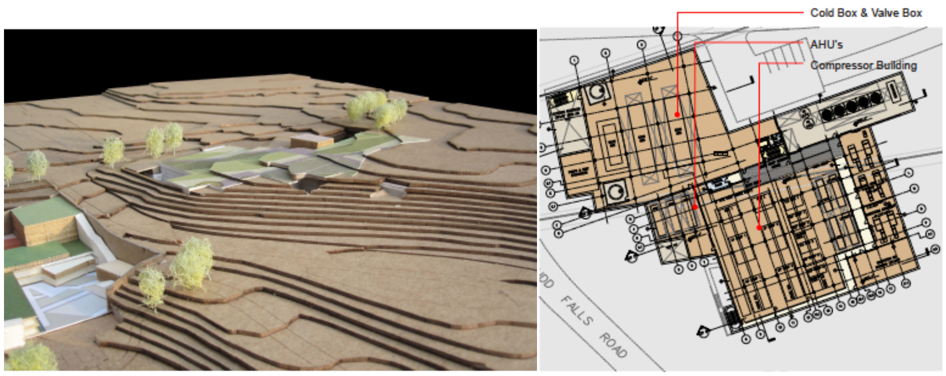
Figure 4.3.4: First-floor level showing laboratory, office and courtyard space. The injector room is located at the upper right of the figure.

building walls will not be required to bear loads from the hillside above. The retaining wall along the north side will continue to the west to allow for the construction of the Wilson connection tunnel by a cut and cover technique. Smaller retaining walls will be required along the south side of the building in order to allow for the excavation to take place. The east Laboratory Building will be constructed on shallow footings and incorporate a permanent under-slab drainage system.

The Cryoplant Building will be founded on shallow footings between 20 and 40 ft below the current ground level. The building walls are designed for permanent soil and water loads; a combination of cut slopes and temporary retaining walls will be required to form the excavation.

Both the CESR connection and the Linac tunnels (Fig. 4.3.7) will be constructed using tunneling techniques. The CESR connection and turnaround tunnel on the east end of the Linacs will be mined after the soil is stabilized. The Linac tunnels will be made with a tunnel boring machine (TBM). Though previous soil-boring data were available, an additional 17 bore holes were drilled in 2010 along the alignment of the Linac tunnel and in the location of the new Laboratory Building and the Cryoplant Building. In addition to soil samples, permeability tests were done and a few water pressure monitors for long term data acquisition were installed.

The majority of the tunnel alignment is through glaciolacustrine-dense, silty, fine sand, although due to the heterogeneity of the ground, it is likely that lenses of coarser, more permeable glaciolacustrine or glaciofluvial material will be encountered. Sections of the tunnel are likely to encounter glacial till, particularly along the northern section of the Linac tunnel. The eastern end of the southern Linac tunnel will encounter rock above the tunnel invert for



(a) (b)

Figure 4.3.5: The cryoplant is recessed into the landscape as shown in the model image (a) on the left. The one-story, mainly underground building (b) houses the compressor room, an electrical substation, and the cold and valve boxes.

about 200 ft. The subsurface conditions at the proposed laboratory building generally consist of a variable amount of both granular and cohesive fill, overlying stiff, silt of clayey and gravelly silt with beds of sand and some gravel lenses, which in turn overlays glacial till material. At the foundation elevation, the material is largely clayey or sandy silt. The slope to the north of the existing parking area, which will be cut and retained by the large permanent retaining wall, comprises largely clays and silts, but also contains some silty sand beds.

Towards the west, near the existing CESR and Wilson Laboratory building, fine grained glaciolacustrine deposits dominate, directly overlying the glacial till material.

Tunnel design

The tunnel sections house the Linacs, their RF power supplies, transport optics, and the necessary utility distribution systems. They include two straight Linac sections 1139 and 1153 feet long, a 527 ft turnaround segment of 139 ft radius, and a 356 ft long connection tunnel to CESR.

Extensive core samples and research into state-of-art techniques and current costs give a high level of confidence that the straight Linac parts will be excavated by an Earth Pressure Balance Machine while the turnaround part and the CESR connection tunnel will be mined due to their small-radius curves. This tunneling approach has been selected to mitigate anticipated risks associated with assumed ground conditions, to employ approaches that have a high probability of success and acceptability within the construction marketplace, to provide a predictable construction cost and schedule, and to avoid unusual/untried technologies for the predicted ground conditions. Previous underground experience at the Wilson Laboratory site includes the original ring tunnel construction in 1965, Wilson Laboratory building construction in 1966, 'Ł0E' addition in 1972, CESR tunnel construction in 1977, and the G–line addition in 1999.

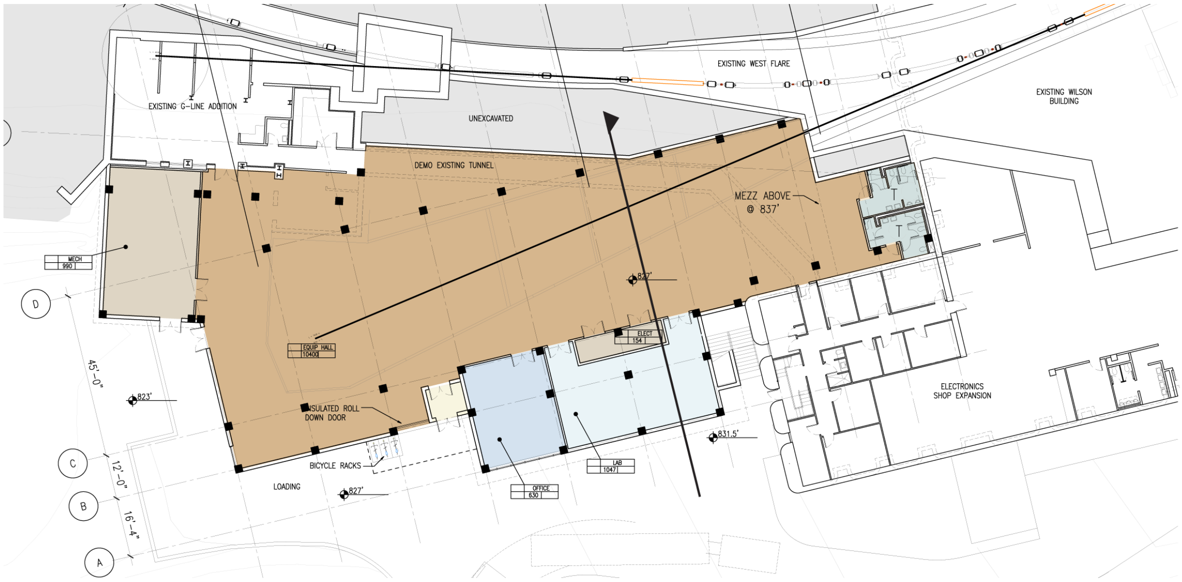


Figure 4.3.6: G-line Annex at level 827'. The building contains a long undulator beamline from a 25 m long ID and a new mechanical room to serve the annex and existing G-line.

4.3.5 Logistics

Code and permits

A comprehensive code review has been performed by the design team for the proposed ERL facility, drawing from the expertise of staff, consultant teams, and the University's Facilities Services Office. The design has been prepared to ensure compliance with all applicable local, state, and federal laws, regulations, and ordinances. Communications and coordination with local (Town of Ithaca) and state code enforcement officials will continue throughout the design and construction process to ensure that appropriate construction and operational requirements are met to maintain compliance.

Permits and approvals will be required from various agencies. Agencies involved in addition to the potential funding agency include the following:

- Town of Ithaca – The town will be responsible for local site plan approval, fill permit, storm water pollution prevention plan (SWPPP) approval, building permit, road work permit, and operating permit.

- New York State Department of Environmental Conservation (NYSDEC) – The NYSDEC will provide approvals of the SWPPP (after town approval) and approvals for construction over two small, unlisted and man-made on-site wetland areas for any work involving new storm outlets to the creek or pedestrian bridge abutment work within the creek high-water flow level. These approval processes have been discussed with the NYSDEC and verified to be largely administrative based on pre-established standards.

- United States Army Corps of Engineers – The USACOE will review the joint US-

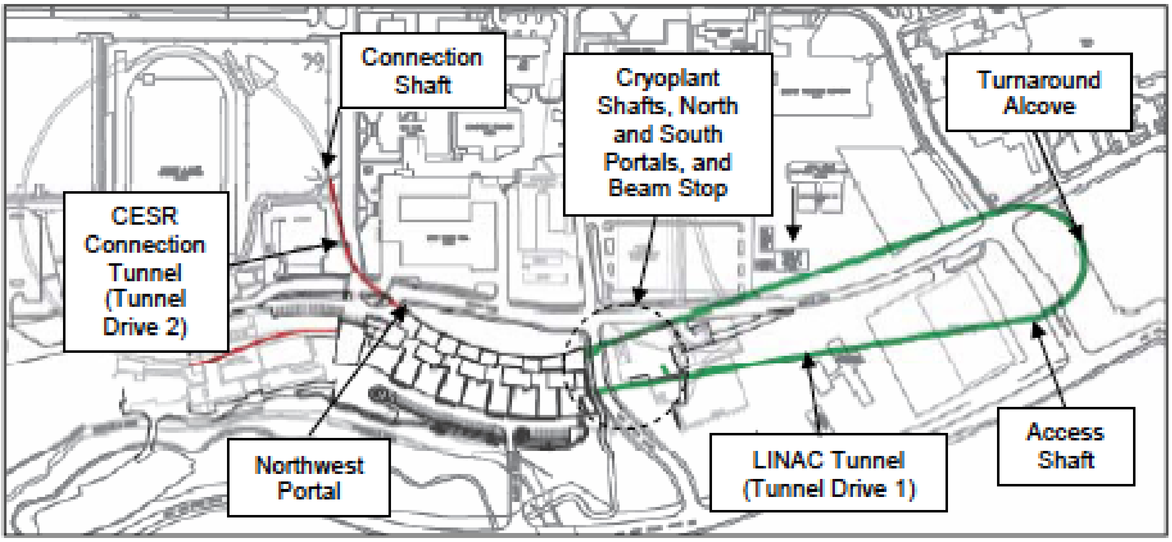


Figure 4.3.7: General arrangement of the tunnel

> ACOE/NYSDEC permit application related to the wetlands and the outfall or bridge work below the creek high-water level noted above. The process typically results in formal delegation of authority to the NYSDEC, with or without recommendations by USACOE.

Cornell may also seek low-interest financing through the Dormitory Authority of the State of New York (DASNY) and could pursue funding from other sources to support construction, operations, education, or research within the facility. No other permits or approvals are anticipated.

Cornell maintains regular communications with the Town of Ithaca and, based on past and present communications, is aware of no serious impediments to obtaining site plan approval for this project. Cornell updates town officials on this and all other proposed development projects through regularly scheduled meetings between officials of both the University and town, often including the university president and town supervisor, and multiple levels of communication through various town officials, such as planning and building staff, and local fire officials. In addition, the University convenes regular meetings with the University Neighborhood Council (UNC), whereby current and future plans are discussed with local neighborhood leaders to ensure that University plans are compatible with community goals and concerns. The future ERL building has been included in the list of projects discussed at all of these venues.

Local site plan approval was initiated in the fall of 2010 and will require approximately 6–12 months. To initiate the process, Cornell has formally applied for preliminary site plan approval, which will be accompanied by a comprehensive environmental assessment in compliance with the State Environmental Quality Review Act (SEQRA). SEQRA is initiated at the first formal site plan review application and, by law, must be completed prior to a formal discretionary approval, such as preliminary site plan approval by the town. While the town requires a great level of specific detail prior to initiating formal approval, including architectural renderings, detailed building material lists and site details, the design of the proposed building is now advanced to the point that this approval process can be initiated.

The SEQRA process, by law, is being coordinated by the lead agency – town of Ithaca – with all the agencies that provide funding and discretionary approvals to ensure that the agencies may address concerns and that the applicant can appropriately mitigate the potential impacts. Cornell has successfully introduced a number of projects in recent years within the Town of Ithaca and surrounding community, including several that included similar attributes, such as a similar scale of building, unique scientific research attributes, centers for national or international study, and high energy-use implications.. Success in receiving the necessary permits for this project without substantial change or compromise is therefore anticipated. Despite the level of detail required and thorough review by the town planning board, the board has never failed to grant site plan approval for any similar University project over at least the past decade. Rather, the town has supported projects built on campus that serve specific educational and research needs.

The University has all the internal and external resources necessary to complete a comprehensive environmental assessment for the project. While the formal SEQRA decision rests with the permitting authority, which will be the town of Ithaca, Cornell officials anticipate no areas of potential significant adverse impact to the environment or local community, based on internal assessments and ongoing communications with community and state officials. The site has already undergone a year-long, rigorous evaluation by the University's Internal Planning Department, and environmental compliance and assessment staff, as part of a formal University site selection process. This process has resulted in the strong preference for the selected site layout as well as recommendations and modifications to the design to eliminate any potentially significant adverse community or environmental impacts.

Public communication starts with open discussion of future plans. This project has already been discussed at a conceptual level with local officials (including a formal sketch plan review at a public Town of Ithaca Planning Board meeting in the summer 2010) and communication has been extended to community leaders within the UNC and formal leaders, such as the town supervisor, county leaders, police and fire officials, town engineers, and planning officials. All of these discussions have been positive and supportive and no critical concerns have been voiced to date. As project financing is approved and the design completed, more detailed outreach (press releases, UNC and community special meetings, and public participation in the SEQRA and site Plan process) will occur to enhance the project's prospects for smooth approval. Typically, such advanced outreach begins when design is sufficiently complete and accurate architectural renderings can be developed and funding assured at a reasonable level.

Environmental impact and LEED certification

As with all construction projects, this project will affect land use, air quality, water use, energy use, and community. To assess such impacts, the project has been internally assessed by the University's Planning and Environmental Compliance staff. Based on our review to date, these professionals have determined that no aspects of the project would create a significant environmental impact, as defined by SEQRA and NEPA, as well as community and social impacts.

To ensure that the project will not have potentially significant detrimental impacts, the project team has worked with University planning and environmental experts to create site plan and massing criteria for the facility and helped select the appropriate site and design standards for the facility. Among other standards, the building will be built to a LEED Silver or higher standard, a University requirement for all campus buildings. It will utilize at least 30% less energy than the LEED baseline energy-code-compliant structure with a design goal of providing all convention heat from 'waste heat' of the cryogenics plant; maintain appropriate buffer distances from natural resources, including an adjacent creek; maintain pedestrian access to and around the site; meet accessibility standards; and remain of a scale consistent with other facilities in the area. Cornell's LEED program is supported by experienced internal and external resources and has had success in defining, meeting or exceeding such standards for all new construction in recent years.

Finally, appropriate feedback received during the formal environmental assessment and site plan process will be incorporated to refine the site-use aspects of the project to improve its value to the local community and mitigate environmental impacts to the extent practical. In our experience, this incorporation of public and agency comment is essential in maintaining strong local relations and has not proven detrimental in maintaining program goals.

References

[1] ARUP. *Energy Recovery Project Definition Design, Volume I Report*. Technical report (2010).

[2] ARUP. *Energy Recovery Linac Project Definition Design, Volume II Drawings*. Technical report (2010).

[3] ARUP. *Energy Recovery Linac Project Definition Design, Volume III - Cost plan and schedule*. Technical report (2010).

4.4 Utilities

4.4.1 Overview

The ERL facility at Cornell will utilize most of the infrastructure of the existing CESR facility and add approximately 195,000 gross square feet (gsf) of experimental, laboratory, shop, office, conference, and other enclosed space in the main laboratory building; 53,000 gsf to house a cryogenic plant; and 14,000 gsf for a laboratory addition on the west side of Wilson Laboratory. In addition, 3,175 feet of a 14–foot-diameter tunnel (inside dimension) will be bored and mined to house the RF accelerating units and beamline components. A layout of the facility, with the new building footprint shown in beige, is in Fig. 4.4.1. The new tunnels include the two Linacs (#1-A and #3–B), the Turnaround #2, and the North Arc #6.

The existing CESR/CHESS facility has an installed electrical service from the Kite Hill substation of $2 \times 8\,\mathrm{MVA}$ at 13.2 kV. The excess heat is removed through a system of five cooling towers and evaporative water cooling units. Additional utilities include steam for heat, 45°F chilled water from Cornell´s lake source cooling facility, potable water, sewage, natural gas, telephone, and network connections.

The ERL facility will make use of much of the CESR/CHESS infrastructure while adding new service connections to accommodate the added building space and higher power requirements of the accelerator. Air handling units, water heat exchangers and pumps, and the normal HVAC equipment are provided for the new laboratory spaces, the cryoplant building, and tunnel. The smaller beams of the ERL require better temperature regulation and lower vibration levels, i.e., close attention to all aspects of the utilities serving the accelerator and experiment floor areas. The parameters and distribution of utilities are described in detail in [1].

4.4.2 State of the art

The ERL Facility is designed to fit the University landscape and blend into the hillside. Emphasis has been placed on meeting functional, community, environmental (LEED), and economic objectives, while meeting the long term planning goals of the University. The facilities employ utility strategies that maximize energy efficiency, technical performance, personnel safety, equipment protection, and applicable code compliance. Each of these priorities relies upon prudent designs, robust control/monitoring systems, and facility integration. Personnel safety and environmental protection are addressed through application of code-specific design requirements and best practices.

4.4.3 ERL performance parameters

Utility performance in support of research involves primarily parameters such as capacity, accuracy, stability, and reliability. Each utility is sized according to an estimated base-load, with a reasonable reserve for future or revised experimental programs. The capacities are noted in appropriate sections below, while performance is generally 100% duty cycle, and reliability is balanced between initial cost, service lifetime, and maintenance requirements. Equipment selections, system designs, and overall performance are based on an annual operating baseline

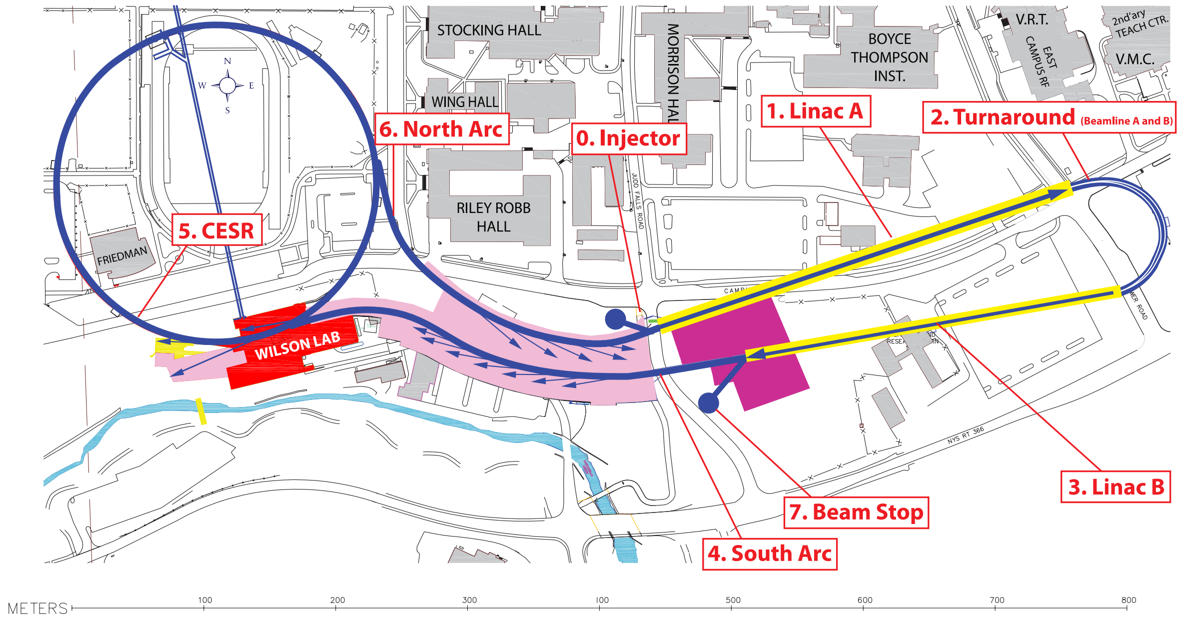


Figure 4.4.1: Layout of the facility.

of 5,000 hours. Special attention is given to utility stability since the stringent ERL performance requirements are intended to achieve precise conditions required to conduct exacting measurements.

The small dimensions of the x-ray beams from the ERL represent one of the facility's main strengths. This property demands unprecedented beam stability in both vertical and horizontal dimensions. In addition, beam optics properties must have sufficient stability to maintain the low emittance (beam size) represented in the parameter list in §2.1.1.

Beamline elements in the ERL are mounted on one–meter–high concrete plinths with an additional 0.37 m of steel supports and magnet iron to the beam centerline. The net linear expansion is approximately 15 μm/°C. Simulations show that rms displacements of up to 200 μm vertically can be tolerated with acceptable emittance dilution after correction as seen in §2.1.15). Evaluation of other temperature-sensitive effects is continuing; meanwhile a ±1°F temperature tolerance on water and air will be specified for tunnel and beamline utilities.

Power supply stability with respect to temperature, line voltage, and warm-up will be commensurate with the calculated sensitivity simulations.

4.4.4 Electrical utilities

Power to the site

Electrical power to the site enters the campus at the Cornell University substation on Maple Avenue (approximately 1/4 mile away in the SW direction, see Fig. 4.4.2). The power is provided by NY State Electric and Gas (NYSEG). The system utilizes three parallel 115kV/13.2 kV transformers to service the main campus. One transformer (37 MVA max

Figure 4.4.2: Maple Avenue substation.

rating) powers the ERL Laboratory complex, though the three transformers are reconfigurable in case of failures. The Maple Avenue substation connects to a new substation inside the Cryogenic Plant via six overhead 13.2 kV lines.

The Cryogenic substation is also a transfer point that feeds the existing Wilson Laboratory fourth-floor substation via six underground 13.2 kV cables. The total estimated peak load for the entire facility is 34.2 MVA.

In 2009, Cornell University installed two natural gas powered, combined heat and power turbine systems, each capable of generating 15 MW continuously. These are fully utilized in colder months to provide heat as well as power to the campus. In principle they can provide ERL enough power to maintain liquid helium inventories in case of a failure in NYSEG's system.

Power distribution for new buildings

Primary 13.2 kV power is brought to the cryogenic plant building via overhead lines from the Maple Avenue substation 1600 feet to the southwest. This indoor substation contains switchgear, circuit breakers, transformers, and related distribution equipment. For the cryogenic plant, the ERL laboratory low voltage distribution, and the Wilson Laboratory fourth-floor sub-feed, 13.2 kV is required. Rectifiers for injector klystrons are also located in the cryoplant building. Two electric utility rooms in the ERL laboratory step down the 13.2 kV to 480, 277, 208, and 110 volts for distribution within the laboratory and tunnels. An underground vault near the turnaround to the east provides 480 and 208 volt three-phase power for the east ends of the Linacs and the turnaround beamline components. The new cryogenic plant requires

Table 4.4.1: Electrical service to the ERL facility

Building Area	Load (MW)	Power Factor	Load (MVA)
ERL laboratory	1.8	0.85	2.1
Existing Wilson laboratory	0.7	0.85	0.8
Key Equipment			
Existing cryogenics plant and laboratory equipment	1.0	0.8	1.3
Linac A	1.7	0.8	2.1
Turnaround (beam-line A and B)	0.7	0.8	0.9
Linac B	1.4	0.8	1.8
South arc	0.7	0.8	0.9
CESR	0.9	0.8	1.1
North arc	0.7	0.8	0.9
Injector klystrons	3.0	0.8	3.8
Cryogenics plant (13.2 kV)	12	0.8	15.0
Cryogenics plant (480 V)	1.8	0.8	2.3
Cryogenics plant (480-V ancillaries)	1	0.85	1.2
Total	27.4		34.2

14.8 MW, accelerator components require 9.1 MW and general laboratories and offices require 3.5 MW (Tab. 4.4.1 and Fig. 4.4.3).

Power distribution for Wilson Laboratory

The existing Wilson Laboratory substations on the outdoor fourth-floor transformer pad (Fig. 4.4.4) will be fed from the new cryogenic substation. Six 13.2 kV cables utilize existing switchgear, and transformers power four substations: US1, US2, US3 and US4. Two other substations are decommissioned. The distribution system within Wilson Laboratory is generally undisturbed. The new G-line laboratory is powered from the fourth-floor transformer pad. Provision to reconnect to the Kite Hill substation is envisaged, providing a backup in case of on-campus failure or in the main ERL distribution system.

4.4.5 Cooling water and cooling towers

Cooling water to the site

Campus Chilled Water (CCW) enters the site from the Campus Road underground water main at two locations. Campus chilled water (45°F) is used for all HVAC loads. Peak flow rate is 1,390-gpm, but actual flow will vary depending on weather conditions and equipment

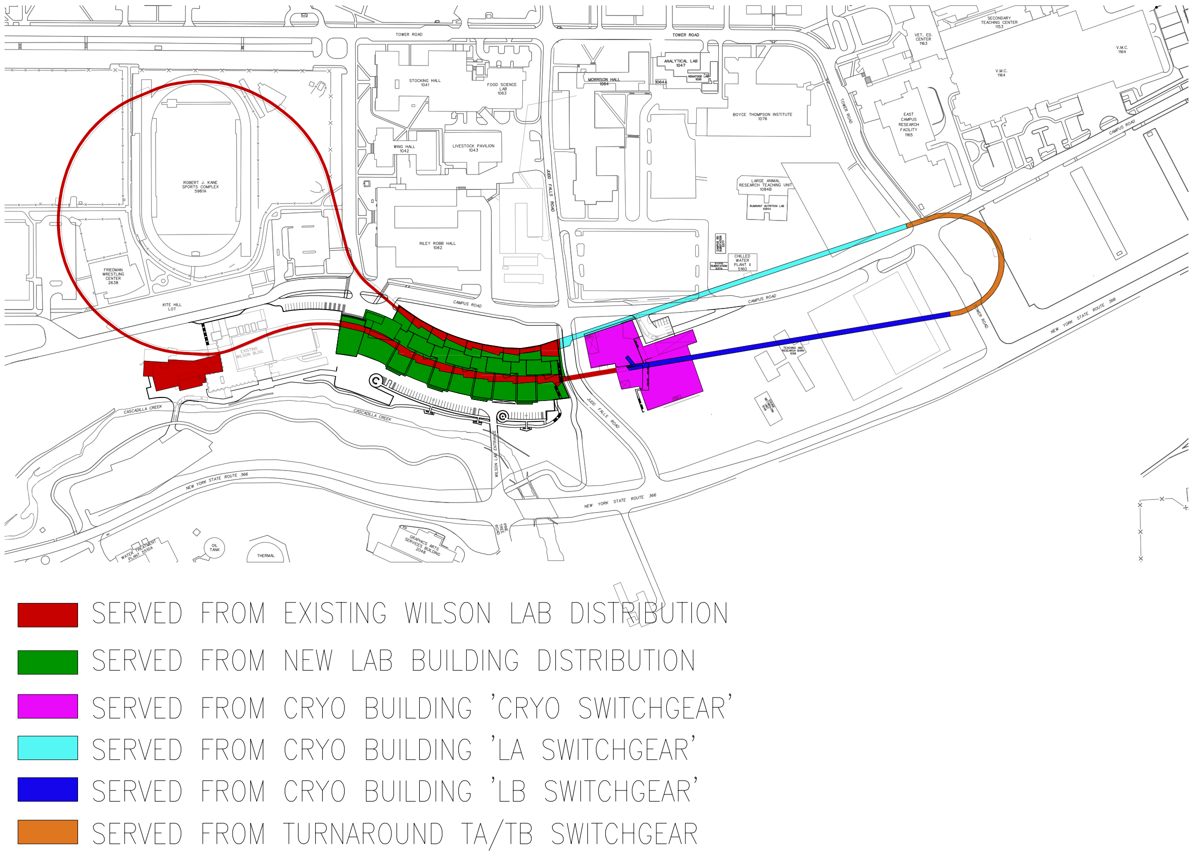


Figure 4.4.3: Electrical service distribution for the ERL.

operation. CCW is distributed to the eight air handlers in six mechanical rooms, and four hutch fan-coil units in the experimental hall. CCW is cooled primarily by nearby Cayuga Lake (Lake Source Cooling Project, see Fig. 4.4.5). The Wilson Laboratory chilled water distribution system remains undisturbed.

LSC draws water through a 2 mm wedge-wire screened intake about 10 feet above the lake bottom, at a water depth of 250 feet. At this depth, Cayuga Lake remains cold (about 39°F) year-round. The cold water is piped to a shoreline heat exchange facility, where the heat is transferred through solid stainless-steel plates to water that circulates to the campus in a secondary pipeline loop. The two water flows never mix. Water drawn from deep in the lake is returned through a diffuser located about 500 feet offshore at a depth of 10 ft. The only change in the Cayuga Lake water is addition of heat; all the heat added to the lake is naturally released during the winter.

Cooling water for the ERL beamlines

The primary experimental water cooling is an 85°F deionized system. Closed-loop systems cool all accelerator components and power supplies through six different flow paths. The total system flow is 1,406–gpm with a maximum return temperature of 120°F. Estimated peak

Figure 4.4.4: The Wilson Lab fourth-floor transformer pad

cooling loads for the sections of the ERL are given in §4.4.2.

Cooling water for Wilson Laboratory

Wilson Laboratory houses the cooling towers in support of the new facilities (Fig. 4.4.6). The existing cooling towers in Wilson Laboratory will be supplemented by two new cooling towers located in the same area. These towers replace the existing building services cooling towers, which are no longer used. Reservoir tanks, heat exchangers, water conditioning equipment, primary pumps, valves, filters and related controls are on the first floor to minimize pressure on the experimental components.

Water chemistry will be carefully controlled for ERL, as is for the CESR cooling systems, by using deionizers for makeup water and nitrogen blankets over reservoir tanks.

Two existing systems remain relatively undisturbed: the 85°F cryogenic and 65°F auxiliary. These two systems support other research work. The existing CESR 85°F and experimental 85°F systems will be integrated into the new ERL–85°F system.

4.4.6 HVAC

The interior spaces of the new laboratory building are served by five variable volume air handling units, and the experimental hall is served by five variable volume air handling units. Five separate mechanical rooms will house the ten units. The experimental hall also has a dedicated exhaust extraction system and four local fan-coil units in the hutches. Offices, conference rooms, restrooms, workshops, dry laboratories, and the chemical laboratory have code specific systems for each particular ventilation requirement.

Figure 4.4.5: The Cornell Lake Source Cooling (LSC) plant.

The new tunnel is served by two air handling units located in a mechanical room within the cryogenics building. The designed air velocity is 450–fpm (minimal) with a single direction exhaust path. As described above, the air supply to the tunnel and beamline areas is controlled to ±1°F.

The building heat ventilation systems get heat from either the heat recovered from the cryogenic systems, or from the university central plant steam system. Cooling and humidity control are provided by the campus chilled water system. Estimated new building peak demands are for cooling 760 tons (2,674– kW) and for heating 15– MBtu/hr (4,400– kW). Lake source cooling provides chilled water with a coefficient of performance (COP) of 25, resulting in a low carbon footprint.

Control and monitoring of the building HVAC system is performed by a direct digital control system that is integrated with the University on-line control system for local and remote access. Wilson Laboratory HVAC systems are undisturbed, except the new G-line facility, and will utilize the existing heating and cooling infrastructure.

4.4.7 Compressed air

The research programs in the new buildings require high-quality compressed air for research, and lower-quality air for general building functions. The high-quality research-grade compressed air is supplied via dual compressors, and include drying and filtration components. Peak flow requirements are 100–cfm, with a 35°F dew point and carbon filtration. The building compressed-air system has a peak flow of 150–cfm with a 45°F dew point and standard industrial oil removal.

The Wilson Laboratory compressed-air system is undisturbed.

Table 4.4.2: Peak cooling loads for the ERL beamlines and injector.

Equipment	Load (MW)
Linac A	1.16
Turnaround (Beam-line A and B)	0.39
Linac B	0.96
South arc	0.44
CESR	0.50
North arc	0.26
Beam stop	1.50
Injector klystrons	1.50
Total	6.71

4.4.8 Liquid nitrogen

The existing Wilson Laboratory LN2 storage system is undisturbed. The new buildings use the existing dispensing station. Delivery truck access to the LN2 tank is maintained. At the present time, the laboratory uses about 300,000 liters/month (250,000 kg/month) of LN2, which is usually received in three deliveries per week of a full truckload. The LN2 usage will drop significantly with the introduction of the ERL, as the new cryogenics plant is designed to operate without LN2 cooling, and the vast majority of the present system is devoted to operation of the helium liquefier. There is still some usage of LN2 for experimental setups in the x-ray beamlines and possibly occasional gas purification for the cryogenic system, but total consumption for the ERL is less than 10% of the present usage.

4.4.9 Communication systems

The standard university phone system extends to all areas and is compatible with Cornell's voice-over-data communications network (EzraNet). Wireless net coverage extends to most areas. Cell phones function in most interior spaces except for tunnels and other similar shielded spaces. Laboratory communications have not been fully defined, but there will be some combination of wireless and wired systems. Emergency communications systems compatible with local fire and Cornell police communications will be provided throughout the buildings and tunnels.

4.4.10 Gas distribution system

The Wilson Laboratory liquid nitrogen boil-off (GN2) system extends into the new building and tunnel. Total additional peak GN2 flows are estimated at 125–scfm. Tunnel flow rates are limited to 25–scfm for safety reasons. User stations require a total of 50–scfm and laboratories require up to 50–scfm.

Figure 4.4.6: The Wilson Lab cooling towers.

4.4.11 Grounding and lightning protection

A complete grounding system is provided in the new laboratory building and will extend to include the cryogenic plant building for the building only, and not for the grounding of experimental equipment. This system includes grounding electrodes, Ufer ground, a connection to the main incoming water pipes and riser connections between the different levels. The Ufer ground wires are connected to the steel reinforcement bars in foundation concrete, which is effective because concrete is more conductive than most soil, increasing the surface area at which the grounding makes contact with the soil on which the foundation is built.

Each substation has a grounding bar connected to ground rod electrodes. It is bonded to the meter side of the incoming water mains. The grounding system is designed to enable protective devices to operate within a specified time during fault conditions, and to limit touch voltage under such conditions.

All extraneous conducting metalwork within the building is bonded. All circuits are distributed with grounding cables, including main feeders and final branch circuits. A dedicated grounding system is provided to communications closets. When required for experiments, a clean dedicated ground is provided from the main substation ground bus to the experiment hall.

The initial design assumes that a lightening protection system is necessary. The assessment may change, based on the shape, size, and height of the proposed building. The building is provided with a UL 97 listed, NFPA 780 standard lightning protection system consisting of a network of rooftop air terminals and copper-down conductors incorporated into the building structure. These terminate in the grounding-electrode networks at the lowest level.

The existing Wilson Laboratory grounding system is not disturbed, except for the extension into the new G–line facility.

4.4.12 Fire alarm and suppression system

New facilities have an addressable fire alarm detection system that includes automatic smoke and/or heat detection, manual pull stations and audible alarms. Visual alarm strobes are positioned along exit paths, at other key points, assembly areas and special use rooms. The system connects to the Cornell central system for continuous monitoring and emergency response.

Smoke detectors are located extensively throughout the building. Duct-smoke detectors are provided for air-handling units, as required by code. Heat detectors are provided to supplement smoke detectors in mechanical rooms and sprinklered, elevator-machine rooms and pits.

Fire alarm strobe and horn devices are installed in all building areas, restrooms, corridors, lobbies, large office areas, and laboratories. The fire alarm horns are independent of any public address system speakers. Pull stations are located at all fire exits and horn/strobe devices are located at all egress routes and at all exits.

The fire alarm system also activates door closures, HVAC shutdowns and isolation devices and monitors detector function, sprinkler flow, and tamper switches. The new buildings will have one main fire alarm panel that interfaces with the existing Wilson Laboratory third-floor fire alarm panel to ensure that the two systems function together. There are additional enunciators at the lower and upper entrances, Wilson control room, and loading dock. The existing Wilson Laboratory fire alarm system is not disturbed, except for the inclusion the new G–line facility.

New facilities will have sprinkler coverage in accordance with Cornell design standards, NY State Fire Prevention and Building Code, International Building Code, and NY State Fuel Gas Code. Other requirements as applicable include Factory Mutual Global, NFPA, ANSI (elevators), and the NY State Cross Connection Control Manual. Normally occupied areas have sprinklers, but the tunnel areas do not.

The new buildings have a combined fire standpipe/sprinkler system and are fully furnished with sprinklers and fire hose stations. A hydrant flow test is required during the design phase. Pre-action sprinklers are used in critical areas as identified by the program. Wet sprinklers are provided in all other areas unless freezing is a likely problem. There are no gaseous or foam fire suppression systems. All drain discharge is to the sanitary sewer.

4.4.13 Drainage

All interior drains are connected to a pumped collection tank connected to the central sanitary sewer system. The drainage of the outdoor klystron pad is to the sanitary sewer by manual release from the covered station that has barriers to prevent an oil release. Roof, surface water, and other exterior draining goes to the storm sewer system. Existing Wilson Laboratory drainage is undisturbed.

4.4.14 Survey and alignment

In order to meet the alignment requirements for the ERL magnet and beamline positioning, reference targets are placed in triplets at least every eight to ten meters, such that the angular spread of the triplets is close to maximum for the given tunnel, building, or area shape for a station midway between adjacent triplets. Typically, one target is placed near the center of the floor and the other two are placed on either wall at a height that maximizes the angular spread of the triplets.

A gyro-theodolite and a laser tracker are used to measure the relative positions of the reference targets and magnet and beamline fiducials, allowing for independent measurement of gravity and north azimuth at every station to within 1 second of arc and 2 to 3 seconds of arc respectively. Distances are measured to better than 7 microns / 1 part per million, with 1 sigma uncertainty.

Reference targets are securely grouted or epoxied directly into the structural concrete or are securely bolted to the Uni-Strut or similar framing integral to the concrete structure. Magnet fiducial fixtures are also securely epoxied into the magnet laminations or other appropriate reference surface. Care is taken to safeguard clear sightlines from station positions to reference targets and magnet fiducials. In addition, staff will mitigate or eliminate dramatic changes in air temperature with location.

Provision is made to enable air-flow in the tunnel to be reduced to below 15,000 CFM during survey work. All support materials, software, and maintenance are provided to ensure adequate efficiency of survey instruments and personnel. Magnet supports are stable and allow for precise alignment of magnets and beamline elements.

4.4.15 Waste heat recovery

Temperature constraints on the process cooling water system limit its practical reuse as a heating source, but the bulk of heat rejected from the site is from the cryogenic plant. The rejected heat (13.8–MW or 1,795–gpm of 140°F water) could be at a usable temperature. While current designs of large cryoplant systems fail to reach this temperature of rejected water, discussions with compressor manufacturers suggest that 140°F is possible with an augmented heat exchanger. Some of this energy would heat the new building, but since the building requirements are only a fraction of the available heat, the remaining heat could be piped as hot water underground to nearby buildings to provide some or all of their heating needs.

Discussions about ERL waste heat heat utilization are part of ongoing campus-wide proposals on sustainable energy use. The Climate Action Plan (see [2]) anticipates continued campus growth, and includes a number of discussions about the potential impacts of large projects, such as the ERL and a proposed computer server/research building for Cornell Information Technologies (CIT). There is a possibility of making the ERL waste heat part of the upgrade of the entire campus steam distribution system. Newer steam installations at Cornell are highly energy efficient and well insulated, so losses are fairly low.

References

[1] ARUP. *Energy Recovery Project Definition Design, Volume I Report*. Technical report (2010).

[2] *Cornell Climate Action Plan*. http://www.sustainablecampus.cornell.edu/climate.

4.5 Cryogenic System

Overview

The cryogenic plant for the ERL will provide helium coolant streams at 1.8 K, 5 K, and 40-80 K, required for operation of the cryomodules in the accelerator. The plant's size is roughly comparable to the largest individual refrigeration plants currently used at other accelerators that operate in the region of 2 K. Although the detailed requirements of each of these plants differ somewhat, we expect to benefit from the experiences at DESY, JLAB, SNS and LHC. As there are presently only two industrial producers in the world with experience in producing such facilities, we have commissioned design studies from Air Liquide [1] and Linde [2] to estimate performance, space requirements, and costs of such a plant. The main body of this section will deal with the broader conclusions of these reports, and the similarities and differences between the two approaches. Because of the specialized nature of the refrigeration system and the manpower requirements involved in producing it, we would plan to contract with one of these companies, based on eventual bid price, to provide construction, assembly, and commissioning of these plants. The civil engineering, architecture, and construction of the buildings to house the equipment will be designed separately to ensure compatibility with Cornell's more general site plan for the facility.

Several additional considerations are important in addition to delivery of adequate cooling power at each requisite temperature. Among these are: reliability of operation (% uptime), efficiency of operation (the electric power required is a major factor in overall system operating costs), ease and speed of cooldown and warmup operations, control stability, and 'maintainability' with a small cryogenic staff. Other, less general issues have dictated some aspects of the cooling scheme and the facility siting such as low vibration levels required for beam stability, avoidance of liquid nitrogen in the tunnel for safety reasons, and a preference for minimizing length of cryogenic transfer lines.

State of the art

The most recently completed large 1.8 K helium refrigeration system is that for the LHC at CERN. Each of the 8 individual plants there is sized to provide 18 kW of cooling at 4.5 K, 2.5 kW of cooling at 1.8 K, and a very substantial cooling capacity for thermal shielding at 60-80 K. A measured COP (ratio of work required at room temperature to extract 1 W at low temperature) of 900 has been achieved at 1.8 K, and a COP of 220 at 4.5 K [3]. Our proposed plant is very close in size to a single one of these 8 plants which in the CERN system are distributed at 3 km intervals around the perimeter of the ring. As Air Liquide and Linde each provided half of the refrigeration plants for the LHC system, both companies have had the opportunity to benefit from experience in building plants of very similar performance demands to those of our machine. As may be seen from their design studies, it is expected to be possible to achieve a better COP than has been previously attained. As with each of the 8 LHC plants, the total refrigeration load in our system would be subdivided between two separate plants. This division is very natural; 20 kW equivalent cooling power at 4.5 K represents the largest cold box that can be assembled and transported as a complete unit. Fortunately, some aspects of the above requirements are less demanding than those of the LHC. There is a much shorter distance separating the cryogenic plant from the most distant part of the Linac string and

Table 4.5.1: Total heat loads for ERL cryogenic system

Coolant stream	Design load (kW)	Load with 50% margin (kW)	Approx. standby loads (kW)
1.8K at 16 mbar	5	7.5	0
5K He at 3 bar	4.5	6.8	3 (4.5 K two-phase)
40-80 K He at 10 bar	96	144	5

much less mass to be cooled down; the helium inventory is therefore very much smaller than CERN's, and our Linac is much nearer the surface than at the LHC.

4.5.1 Cryogenic loads on the refrigeration system

The cryogenic loads for the proposed ERL are summarized in Tab. 4.5.1 The detailed breakdown of the contributions to static and dynamic components of the heat loads at each temperature level have been discussed in more detail in the section describing the cryomodule design, but this table provides the basic information required for determining the capacity of the refrigeration system. The first column of the table indicates the desired properties of the three coolant streams to be supplied, and the second column describes the expected loads in normal operation. Because there is inevitably some uncertainty in the actual loads that will be experienced in practice, the third column indicates a 50% safety margin added to the design loads, and it is this number that we have asked vendors to consider in their design studies for the cryogenic plant. Finally, the fourth column indicates the power that would be required to hold the system in a 'standby' configuration, with no beam and no RF power applied, but with the superconducting cavities held somewhere close to 5 K and the 80 K shielding system in operation. In the two design studies, we asked the vendors to consider the costs for design of a plant with the 50% margin, because the greatest uncertainty is in the Q of the cavities at 1.8 K. It is crucial that the plant size be adequate to meet the performance goals for the machine, but estimation of operation costs were to be based on the actual design load, as this is the most likely power demand when the machine is constructed.

In eventual operation of the machine, it is expected that the accelerator will be providing beam for experimenters for about 5000 hours per year, while the remaining 3700 hours per year will be devoted to some combination of accelerator/x-ray beam studies and maintenance, with possibly 3000 hours per year at the much lower power 'standby' level of operation.

It should be noted that the machine has been designed to operate in several different 'modes' to optimize different parts of the total available parameter space for different categories of experiments as described in §1.3.3. While these different modes will potentially place considerably different demands on the 5 K and 80 K parts of the cryogenic system, the 1.8 K system has a load which is dominated by the RF field gradient in the cavities and will be largely unaffected by the mode in use.

The particular choices for the temperatures of the three different coolant streams result from optimization of several factors. While these are discussed in more detail in the cryomodule design section, it is useful to summarize here the broad conclusions. The choice to operate the cavities at 1.8 K rather than 2 K was based on modeling that indicated that the improvement in cavity Q should reduce the heat load by enough to outweigh the change in COP for the refrigeration system. The choice of supercritical helium at 5 K for the thermal intercepts is related to a desire for single-phase flow for easier control, in addition to a need to maintain the intercept points far below the critical temperature of niobium. The supercritical helium has a very useful increase in heat capacity in the immediate vicinity of the critical point, so there is less degradation of the coolant stream temperature at the far end of the Linac string by operating at a pressure not far above the critical pressure. Operating with single phase flow also eliminates the generation of microphonic noise from bubble generation that would result from 2-phase flow, which may be very important in this application. Because there will be very high heat loads in the 70 K range from the dissipation in the low-temperature higher-order-mode (HOM) absorbers (and to a lesser extent from the input couplers), it is wished to use a single flow stream for removing this heat over the length of a half Linac, it is necessary to allow a significant temperature rise over the length of the machine. Thus it is intended to supply He gas to the machine at 40 K, but return it to the refrigeration system at 80 K.

Temperature stability and control requirements are very different for the three different coolant streams. In each case, it should be noted that there will be significant gradients along the length of the Linac, which will result in temperature differences between similar components at the two ends of the machine. These are much larger than the tolerable fluctuations at any given cryomodule. By far, the most stringent demands are on the 1.8 K coolant stream where the pressure of the helium experienced at any given cavity needs to be maintained to about 0.1 mbar, while from one end of the Linac to the other, under full field gradient conditions, the gas flow in the return pipe will produce pressure differences more than ten times greater. A significant control challenge will come from the very great change in thermal load on the 80 K part of the refrigeration system as the beam current is rapidly changed from 0 to 100 mA and the cooling load is increased 20 fold.

4.5.2 Overview of design considerations for refrigeration plant

A number of sometimes conflicting preferences involving cost, reliability, efficiency, maintenance, appearance, flexibility, and convenience of use enter into the choice of design constraints applied to the refrigeration plant. The initial capital cost of the cryogenic system as well as the high energy costs of its operation over the life of the facility represent a significant fraction of the total project budget, so reducing these costs has been the primary focus of our design. To deal with the relative importance of capital costs and continuing operating expenses, we requested that the potential vendors try to minimize the sum of the initial capital outlay and the operating costs for the first ten years. There is a tradeoff here, because an improvement in energy efficiency that improves operational costs usually tends to boost the initial costs because of a need for better heat exchangers and possibly more stages of compression for higher isothermal efficiency. Because we anticipate running at full cryogenic load much of the time, it could be advantageous to strive for higher-than-present operating efficiency. Existing large-capacity refrigeration systems at 2 K or lower operate at accelerator laboratories that have similar intent to provide good ‘up’ time and low power consumption; thus, refrigeration manufacturers have already pushed design optimization in this general direction.

Reliability is also a major concern, as the experimental schedule is very intolerant of unscheduled down time. The impact of an outage of any sort depends on the time to restore the plant to full cryogenic operation; that time will generally be much greater than the time needed to replace failed components, even ones readily obtainable. Some items, however, have very long lead times; e.g. cold compressors, turbines, and some of the large room-temperature compressors. These individual components are considered to have extremely low risk of failure, but would potentially have a lead time of many weeks to obtain a replacement because they are not off-the-shelf items. It will be necessary to stock an inventory of such critical parts to insure against shutdowns. The attendant cost may well amount to a small percentage of the overall capital cost. One might try to minimize this inventory stocking by minimizing the number of types of different long-lead-time components by having a more modular design, but it is impractical to design enough capacity into parallel modules of smaller size to allow a single one to be taken out of service for maintenance or repair while the accelerator remains in operation, as is sometimes done in smaller facilities. There are major savings in both cost and complexity by making the individual compression and refrigeration units as large as possible for the application, and complete redundancy would greatly increase the cost.

Distribution of the coolant streams to the tunnel from the cryoplant are discussed in the following sections. Within the Linac, the incoming and returning fluid flows are fully contained within the cryomodules; design considerations for the sizing of the cold piping are discussed in the cryomodule segment of the document. There are no separate external cryogenic lines paralleling the cryomodule strings in the tunnel.

4.5.3 Summary of specific proposals for plant by potential vendors

Below we discuss the initial studies for the plant, made by Air Liquide [4] and Linde [2], and a later follow-up study by Air Liquide (also in [4]). How well do these studies match the design criteria, what are their initial costs and operational costs, and what are their differences? The latter study by one of these vendors was to consider implications of some changes in the layout of the Linac sections and changes in the relative location of the cryogenic plant, along with some small modifications in the estimated heat loads that have evolved since the initial study. Because the design studies contain proprietary information, access to these references are on a private access website available to reviewers of this design study and to Cornell researchers, but the detailed content must not be distributed elsewhere without specific permission.

Similar features of the two design studies

Many decisions about the overall refrigeration system configuration were the same in the two studies. Here the shared design concepts are discussed.

The physical location of the cryogenic plant will be near the surface level, even though the tunnel for the accelerator will be typically 30 meters below the surface. This will substantially reduce construction costs as well as minimize the areas where cryogenic fluids and confined spaces present safety risks. Location near the surface also provides some level of vibration isolation between the heavy rotating machinery in the cryogenic plant and the highly sensitive cavities, focusing magnets, and insertion devices in the beam line. The small extra pressure head from the elevation differential in fact can be of some utility in distributing the superfluid helium liquid through the length of each of the two Linac sections, but is still small enough so that the added pressure drop in the returning vapor phase does not significantly reduce the efficiency of the refrigeration process. The elevation difference between the refrigeration plant and the tunnel does create the need for large cryogenic vertical transfer lines. The intent is to supply the two halves of the tunnel separately with transfer lines going through two separate vertical shafts of 3-4 m diameter, which will also provide access for other utility and communications lines.

The fundamental cooling process – expanding compressed helium gas to do work against low-temperature expansion engines, then recycling the lower pressure exhaust gas through a series of heat exchangers and subsequent compression – is a variant of the Carnot process that has been in use for many decades. Refinements of the details of the process have been ongoing throughout this time. Both vendors are taking advantage of their experiences in design of the LHC refrigeration system as a close starting point in the detailed process design for this system. Not surprisingly there is great similarity in the number and size of specialized components such as cryogenic turbo expanders, cold compressors, and brazed-finned aluminum heat exchangers, although each manufacturer has proprietary variants of these components.

Both vendors intend to fabricate major modules at their own construction facilities and then ship these modules to Ithaca for final assembly on site. This approach is customary because of the special facilities needed to build the major cryogenic vessels, but does put constraints on the maximum size of components because of the need for road transportation. The vacuum vessels for the heat exchanger units are thus effectively limited to approximately 20 meters in length and 4 meters in diameter, and both vendors found it necessary to divide the cooling load between two separate refrigerators. Past experience has already demonstrated that the maximum cooling power of a single cryogenic refrigerator is limited to about 20 kW (of 4.5 K equivalent cooling power) if furnished in transportable modules. As mentioned earlier, each of the 8 cryogenic stations for the LHC also supports roughly this two-refrigerator cryogenic load, so the intensive prior design experience in a very similar capacity range has already undergone in-the-field testing.

For smaller helium refrigeration systems, it is often found to be economically effective to use liquid nitrogen (LN2) pre-cooling as an adjunct to the higher-temperature gas heat exchangers to take advantage of the very high efficiency of commercial LN2 plants. It was investigated whether this might also be of economic benefit in this area even for a large capacity plant because of relatively high electricity rates and relatively low LN2 costs. Both vendors found that it would not be cost-effective to use LN2 as a component of the flow process in this plant. Moreover, the quantities of LN2 required – several truckloads per day – would have made operations very vulnerable to area road conditions during the winter. There will, of course, be a need for smaller quantities of LN2 in experimental areas, and perhaps occasionally for purification operations at the main cryogenics plant. For these purposes, however, the existing LN2 tank and fill procedures will be quite sufficient.

Selection of compressors for the refrigerators appears also to adhere to common design thoughts. A compression ratio of 3 to 4 seems to be selected as the best compromise between few stages of compression (lower capital cost, higher reliability because of fewer machines) and many stages of compression (better isothermal efficiency, as inherently the compression process is nearly adiabatic in high-throughput screw compressors). Because of greater difficulty in adjusting the compressor throughput at low temperature, adjustment of plant capacity to meet the instantaneous refrigeration needs is done with the room temperature part of the compression.

There is a considerable amount of helium inventory that must be recovered and stored when the accelerator is warmed up for maintenance, repairs, or upgrades. The alternatives for this storage are in the form of high-pressure gas storage at room temperature, or in the form of liquid at cryogenic temperatures. Although it has been traditionally more common to provide this storage in the form of high pressure gas, it currently seems more economical to store the helium in liquid form. This is also preferable from the standpoint of visual aesthetics, since the liquid storage option involves a much smaller container volume.

Differences between the two design studies

Despite the overall strong similarities between the two vendor studies, there were also some striking differences in the approaches taken. One vendor proposed making two basically identical refrigerators in parallel, each providing half of the cooling power at the 1.8 K, 5 K and 40-80 K stages. The other vendor recognized that roughly speaking, the refrigeration load was equally balanced between the 1.8 K component and the 5 K and 40-80 K coolant streams. Thus they were able to devise a scheme where one plant provided just the 1.8 K cooling, while the other dealt with the higher-temperature shield cooling demands. Their study of the process diagram indicated that they could attain rather higher net efficiency of the cooling process with that scheme. If realized in practice, it could result in long-term operational cost savings. Somewhat different control schemes would obviously be in effect for each refrigerator in this plan, but there could be operational advantages when changing experimental conditions for different types of machine operation. For example, changing the beam current is expected to have very little effect on the 1.8 K cooling load because the heat load depends mostly on the field gradient in the cavities and very little on the beam current, while the 80 K cooling load for the HOM loads will depend very heavily on the beam current, and much less on the field gradient in the cavities.

While both vendors use low-temperature turbo expanders to extract work from the incoming gas streams and cold compressors to re-elevate the pressure of the out coming gas streams from $\sim$ 15 mbar to atmospheric pressure, each vendor makes its own versions of these key components, using different control schemes, different types of bearings, different in-house manufacturing methods, and different balancing techniques. While each company is certain that its version is the best, it is clear that both systems have an enviable record of reliability in the field. Because there is a long lead time to fabricate each of these cold rotating components, it is almost certainly a necessity to stock a set of spares against the event of a failure. In practice it appears that such spares seldom if ever get used in the refrigeration plants at many high-energy accelerators.

Comments from an external review of the design studies

Subsequent to our receipt of the design studies from the refrigerator manufacturers, we invited an external review panel to discuss their thoughts on the cryogenic system. The first strong opinion they expressed was that from the standpoints of flexibility, maintenance, and partial redundance in the two systems to have two identical refrigeration plants rather than the split functionality of one high-temperature system and one 1.8 K system. It was felt that these considerations were much more important than a small increase in operational efficiency expected in steady-state operation from the differentiated plants. A number of the other issues specifically addressed are mentioned below.

First, it was felt that it is very important to specify performance not only for the steady-state performance of the cryogenic system under the design load, but also under conditions of initial cooldown, upon sudden changes in parts of the cryogenic load, and in graceful recovery from power failure.

Secondly, it was felt that in the final design of the plant that as much flexibility as possible should be incorporated into the relative refrigeration power at the three different heat extraction stages. The reason for this is twofold. Although we have specified that the machine should be capable of delivering 50% above the design cooling loads in order to ensure against our uncertainties in actual cooling requirements, sources of possible error in simulations of the cooling demands at the different temperature levels are different, and the proportion of design power needed at each stage could be considerably different. Further, operating conditions could vary considerably. At a beam current of 10 mA instead of 100 mA, HOM power which dominates the 40-80 K heat load and represents almost 1/4 of the total wall plug power for the cryoplant would only be 1% as large. During the initial commissioning stages of the machine, there might be a period of months when it would be natural to run with such a lower beam current, and it would be desirable to be desirable to be able to operate with a relatively tiny 40-80 K load and the normal 1.8 K heat load. With enough flexibility in the operating characteristics of the refrigeration plant, it might even be possible to run at 10mA with a single refrigerator rather than two in parallel if all the other heat loads meet the design values.

Thirdly, we need to recognize that the ratio of dynamic heat load to static heat load is dramatically higher for our machine than what is found at any other large accelerator facility. The refrigerator will need to be designed to accommodate as quickly as possible to the large changes to the heat load in the 1.8 K system when the cavity accelerating rf fields are ramped from 0 to 16 MV/m, and to the factor of 10 change in 40 K heat load when the beam current goes from 0 to 100 mA. The complete recovery of the refrigeration plant to such giant changes in heat load may well require hours for complete stability. In the short run it will be necessary to compensate by electrical heating circuits distributed in the cooling loops in the individual cryomodules, but we would strongly prefer to be able to ramp these compensating power levels on and off at as high a rate as possible, so that we do not have to provide maximum power for refrigeration even if the field is down or the beam current is low. Fourthly, for testing the refrigeration plant capability on commissioning, it will be necessary to have test loads built into the system to verify that the required refrigeration capacity at each temperature level is in fact met, without the added complication of the entire linac being first installed! Several specific considerations will need to be remembered in the cryoplant design. In many large 2 K cryogenic systems, there are separate supply and return lines outside the cryomodules for each cavity. It is typical in such cases for the heat exchange between the 2 K return gas and the supply liquid before the JT valves to be done in a number of smaller discrete heat exchangers distributed along the accelerator, rather than in a single larger heat exchanger needed for our design to have adequate efficiency. During the pre-cooling phase of operations, it will be necessary to have several bypass valves within the refrigerator cold box to allow either the supply gas or the return gas to bypass parts of the heat exchanger system during cooldown. Such bypass valves were not specifically indicated in the simplified process flow diagrams in the original commercial design studies.

As we are planning to utilize liquid helium storage rather than medium pressure gas storage for the majority of our helium inventory, it may be desirable to have a small separate helium liquefier purely to be operated for extended accelerator down periods in order to provide reliquefaction capabilities for boiloff from the two 13,000 liter dewars which will be used for storage. The main refrigeration plant is grossly oversized for this activity.

Our initial planning for the 40-80 K cooling gas had assumed a somewhat arbitrary pressure of 10 bar for the helium in the loop. The studies generated by the cryogenics companies actually specify 20 bar for this helium in their process flow diagrams. This turns out to be the natural pressure at which to provide this coolant stream in order to optimize plant efficiency, and is not easy to modify. The change in pressure makes relatively little difference in the design for the heat exchange within the cryomodule, but does increase somewhat the total helium inventory for the overall system in operation.

The cryoplant designers will have to be quite careful in the design of the final cooling stage for the 5 K supercritical helium cooling loop. It is desirable to operate near the critical point of the helium fluid phase diagram to take advantage of the enhanced specific heat in this region (which results in smaller mass flow of helium and hence smaller compressor capacity), but it is important to be aware of high compressibility of the fluid in this region, and not to drop into a 2-phase part of the phase diagram.

4.5.4 Building requirements to house the refrigeration plant

General architectural considerations are presented in §4.3. Here we present the areas needed for the plant, the size of the equipment, the desired separation of the vibration-producing compressor building away from the rest of the operations, and the desirability of having the final distribution system near the tunnel.

The location of the cryogenics plant is planned to be near the existing surface level, positioned vertically above the west end, of the two Linac tunnels. The floor level of the plant would be at approximately 20 meters above the beam line at this point. A plan of the building layout is shown in Fig. 4.5.1

The building space is divided into several sections. The first, the 'refrigerator building' in the northwest corner, (upper left in the figure) contains the very large cold boxes which are located as close to the tunnel as possible, in order to minimize the length of vacuum-insulated cryogenic lines delivering the cryogenic fluids to the two halves of the Linac. While very massive, these components will produce very little vibrational noise that might degrade Linac performance. The cryogenic transfer lines going to the two halves of the Linac will drop down to the level of the beam line through the two 3 m diameter access shafts. The shafts will also provide a transmission route for various utilities including some electrical, communications, and air handling lines. There will be two cryogenic transfer lines down each shaft, one with a 40 cm outer diameter and the other a 45 cm diameter. The exact size and layout of the cold boxes in this room would depend to some degree on which vendor was selected and on final machine design, but in any case would fit within the space shown in Fig. 4.5.1. The cold boxes are expected to weigh in the range of 50 to 100 tons apiece, so will require the services of

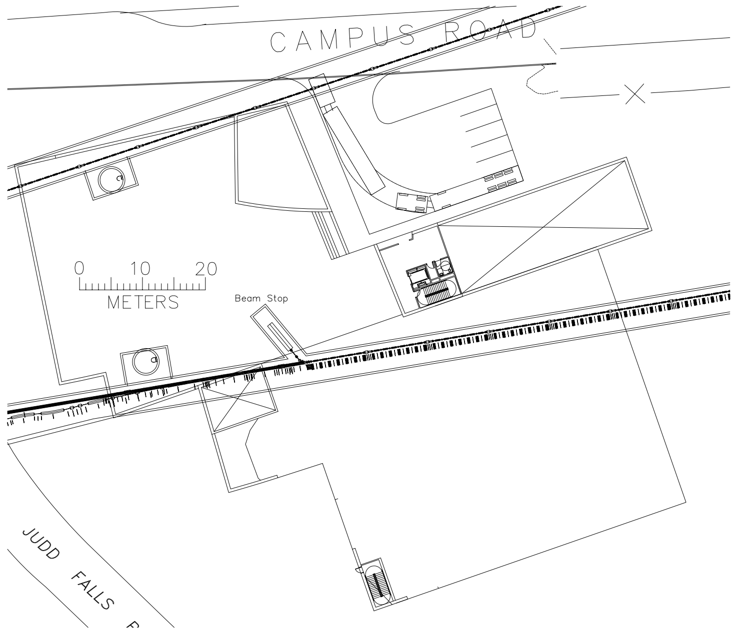


Figure 4.5.1: Plan layout of the cryogenic plant, showing the outline of the buildings and the adjacent roads in black, and the underground Linac tunnel in gray. Figure taken from [5].

a large external crane for initial installation. It is not expected that the entire units would normally have to be removed after the initial installation, but it is necessary to be able to service various components, such as the cold compressors and turbine expanders at various intervals. We provide adequate clearance around the relevant cold boxes to allow extraction of these components should the need arise. It is anticipated that a full overhead crane system would not be installed, but that an overhead monorail lifting system to aid in the servicing of such components would be used. Because this would be a relatively quiet segment of the building, it is intended that control room space for plant operators would be located off this part of the building to reduce the need for acoustic insulation.

The second major area, located in the southeast corner of the building, contains several large compressors which are the main consumers of electrical power for the refrigeration system. The compressors are also the greatest source of mechanical vibration, which might be detrimental to Linac operation. These compressors also have very considerable weight, and sub-components will occasionally need to be moved for maintenance or potential replacement during the life of the facility. The intent is to provide local lifting means for maintenance removals and re-installations. This requires somewhat more horizontal aisle space than would be required for service with a full crane system, but reduces overhead clearances, which is important for visual impact in the area where the building is to be constructed, and also eliminates considerable costs for the crane. In addition to the compressors in this room are other ancillary services such as oil separation equipment. The piping for the low pressure helium coming into the compressors from the cold boxes, and for the high pressure helium returning to the cold boxes is envisioned as being conducted near ceiling level in a rather wide aisle between the two building segments. Because of the vibration produced by this rotating machinery, even after mounting on vibration-isolation pads, it is desirable to have the compressor room located relatively far from the Linac. Compromises are made here, as at most cryogenics plants, because of a desire to reduce piping lengths (initial capital cost and energy efficiency are both improved), and simplifications of operations and service by having the cold boxes and compressors in nearby proximity. The compressors are positioned as far away from the tunnels as the site conveniently permits. There is also a need for a high level of acoustic isolation in the audio frequency range, since the compressors produce an intense sound level in operation. For mitigation, the intent is to emulate the CERN compressor plant's acoustic isolation installed on the walls and ceiling of the building.

There is always the need for helium storage, in gaseous or liquid phase. Here proposed is storage of our helium in liquid form, as this seems to be cheaper and to afford a lower visibility footprint. The liquid helium storage is to be placed outside the building in an area referred to as the 'lift pit', shown on the west side of the building (left side in the figure) with diagonals drawn over the area. Having the liquid helium storage outside minimizes the oxygen deficit hazard, which is always potentially present when dealing with either cryogenic fluids or high pressure gas storage. The lift pit will also house the cooling towers; the waste heat generated by gas compression requires several megawatts of (room temperature) cooling capacity. The lift pit also provides access for the large equipment skids in the building, either for delivery or removal. It is possible to transport any individual skid from its location in the compressor room into the lift pit, thence by a mobile crane to a flatbed truck at ground level (schematically indicated in the upper left of Fig. 4.5.1). By placing the helium storage dewar and the cooling towers in this pit, they are less visually obtrusive than if built at ground level.

Building access (stair and elevator) to the outside world, and interconnection between the different segments of the building is made via a multi-story central section adjacent to the lift pit. The shafts affording access to the tunnels for the cryogen streams, various communication and control lines as well as emergency personnel ingress and egress are of sufficient size for conducting the tunnel ventilation streams. The needed air-handling units are therefore installed in the refrigerator building.

Finally, there is an electrical substation distributed around the periphery of the compressor building, as this is the specific destination for much of the additional electrical power requirements of the ERL project; it occupies a significant fraction of the floor space in the compressor section of the building.

4.5.5 Installation and commissioning time scale

The procurement, construction, installation, and commissioning of the cryoplant is discussed in the ARUP cost and schedule document.

Much of the initial fabrication will be done off-site, but there is a very substantial lead time involved. When it is delivered there must be building space available for installation of the major equipment skids. The final interconnection plumbing will also take time, as will the acceptance testing of the machine using dummy cryogenic loads.

The commissioning of the cryogenics plant and testing of its capacity does not need to wait for the completion and installation of the cryomodule strings in the Linac. Operating capacity will be tested with dummy thermal loads, which will in themselves represent some design challenges because of the large surface areas required to achieve kilowatts of heat transfer to a gas stream in a reasonably compact assembly.

4.5.6 Expected refrigeration plant operation and maintenance issues

Each vendor has indicated that a stockpile of critical spare parts for emergency repairs would be between 1 and 2% of the initial cryoplant capital cost. Maintenance schedules need to be observed for all this apparatus; we anticipate that there will be down periods of some extended duration (several weeks) occurring once or twice a year that will be utilized for scheduled maintenance. We expect very little unscheduled downtime. Experience from CERN initial studies on the first LHC test lines indicate $< 5\%$unscheduled downtime [6], and at JLAB there has been $< 1\%$ unscheduled cryogenic downtime after their 1.8 K plant came into normal operating mode [7].

4.5.7 Safety

The general safety plan for the project is described in §4.6, but some specific concerns to the cryogenic system will be mentioned here.

Personnel safety

Particular areas of concern for personnel safety include:

- Oxygen deficit hazard, because of the large quantities of compressed or liquefied gases of trapped cryogenic fluids if pressure relief systems are not appropriately designed and incorporated
- High voltage distribution for compressor motors, since for compactness and efficiency large motors are designed to run at several kilovolts
- Hearing loss if use of ear protection is not strictly adhered to in the high acoustic levels around the compressor room.

All of these items are generic to large cryogenic systems around the world and have effective safeguards if they are carefully applied. Owing to a long history of using cryogenic systems at the Cornell storage ring, there are in place safety standards and monitoring procedures that can be modified in a straightforward way to handle this larger cryogenic system.

Equipment protection

There are also specific concerns about equipment protection. High in this category (in the context of the recent splice failures in magnet leads at CERN that led to extensive damage to equipment and time delays) is explosive pressure development in the gas system because of inadequate pressure venting capability in the event of catastrophic vacuum failure. While the stored energy in our system has a different character from that stored in the magnets at CERN and also utilizes a much smaller liquid helium inventory, great attention will be given building in adequately dimensioned lines for rapid gas relief in the case of massive rapid vacuum failure. A note on the pressure/temperature evolution in one half of the Linac subsequent to a catastrophic insulation vacuum failure shows that we require ejection of most of the helium contents in less than 1 minute to avoid excessive pressure rises. It also shows that the helium gas return pipe will provide adequate throughput to enable gas to be ejected safely outside the tunnel [8].

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4.6 Safety

4.6.1 Introduction

The ERL will be located on the eastern edge of the Cornell campus. As part of Cornell, it will benefit from and be part of the University's safety environment and safety services. The Cornell Safety Policy (see [1] states "Cornell University strives to maintain a safe living, learning, and working environment. Faculty, staff, students, and other members of the Cornell community must conduct university operations in compliance with applicable federal, state, and local regulations, University Health and Safety Board requirements, and other university health and safety standards." CLASSE staff members and employees are expected to conduct their work in a safe and responsible manner. Project leaders, managers, and supervisors are expected to plan their work with safety designed into both hardware and process, and to ensure that their employees have all the information, training, and equipment required to do their tasks safely. The senior staff are responsible for creating a safe infrastructure and an environment where all the staff take responsibility for their safety and the safety of their coworkers seriously. Ultimately, the CLASSE director is responsible for safety at CLASSE.

The CLASSE Safety Committee members are appointed by the director and are responsible for implementation of the Cornell policy and safety policy specific to CLASSE. The safety director screens new processes, procedures, installations and apparatus for compliance with health and safety regulations, for conformance to any safety standards that might apply, and for protection from any hazards these do not adequately address. The director also works with local experts to come up with a plan that achieves their goals safely. Depending on the scale of the project or nature of the hazard, the safety committee or an ad hoc committee may be asked to conduct a formal review. Representatives from the Cornell Department of Environmental Health and Safety (EH&S) are invited to safety committee meetings and reviews. A CHESS safety sub-committee reviews experimenter proposals. The laboratories share portions of Wilson Laboratory and have fully coordinated safety programs. This includes participation of safety personnel of each laboratory in reviews of hazards in either laboratory.

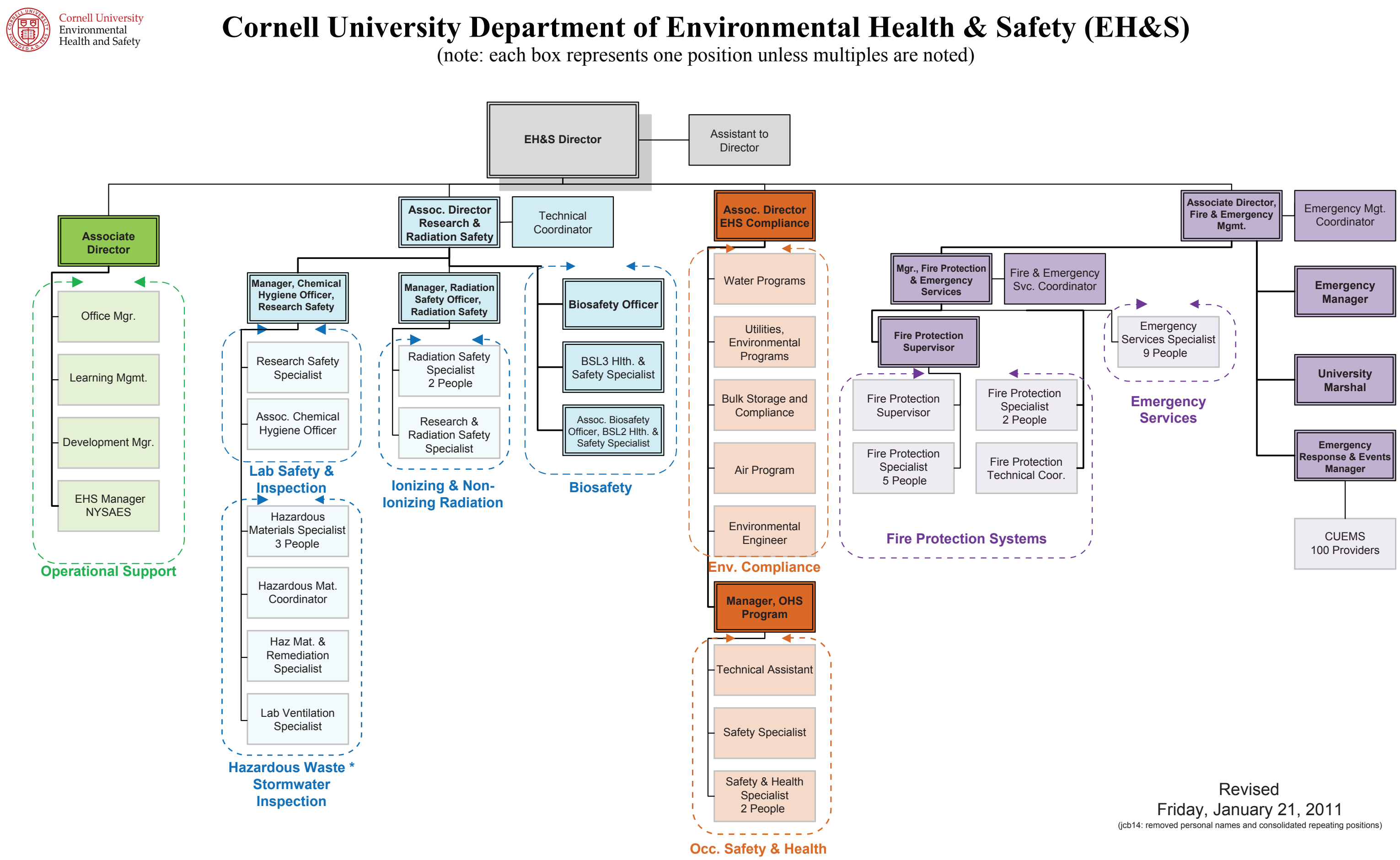

Figure 4.6.1: Organizational chart for the Cornell University Department of Environmental Health & Safety (EH&S)

CLASSE staff members and employees receive lab safety and hazard awareness training when first hired and at regular intervals. This enables them to recognize the variety of potential hazards arising from the wide range of technologies used in our accelerator environment and the specialized training they may need for particular assignments and for proper response in emergencies. In addition, their supervisors review with them the specific additional training required for their work assignments. Ultimately, the strongest element of the safety program is an atmosphere or environment built over more than 50 years of safe, responsible behavior at all levels within the laboratory.

Cornell's EH&S provides and monitors programs in laboratory safety, occupational safety, fire safety, and emergency response and environmental compliance that implement and support the Cornell Health and Safety Policy. Its organizational structure is shown in Fig. 4.6.1. Laboratory safety programs in chemical, biological, radiation and laser disciplines include consultations, inspections, training, support services, and in some cases a permit process. Occupational safety programs and services include a wide range of training courses, programs in accident and injury prevention, industrial hygiene, OSHA compliance, lockout-tagout, machine shop safety, and safety consultations for new and unusual processes. Cornell's Fire Safety and Emergency Response team supports fire safety inspections by the New York Office of Fire Prevention and Control, maintenance of fire alarm systems, fire suppression systems, fire safety compliance, and a 24/7 Emergency Response Team. In addition they provide many regulatory compliant support services for research activities. In addition to EH&S, Cornell has many other programs to support safety and compliance in research. These include an Institutional Biosafety Committee, an Institutional Animal Care and Use Committee, an Institutional Review Board for Human Participants, a University Radiation Safety Committee, and Gannett Health Services. LEPP and CHESS staff participated in the forming and shaping of many EH&S programs. This has included membership on the University's Safety, Health, Environment and Risk Management Board, membership on the Cornell Radiation Safety Committee (including two chairpersons), and participation on many program audits, department reviews, and search committees. In turn, EH&S provides support for our operations, offering umbrella programs such as those mentioned earlier for activities having safety and compliance issues, auditing many of our safety programs, supplying expertise for procedures, projects and programs, and providing services with substantial compliance-related requirements such as disposal of chemical and radioactive wastes.

4.6.2 Workplace safety

Cornell's EH&S operates a full range of programs supporting workplace safety. They include confined space, cranes and forklifts, electrical, ergonomics, excavations, exposure assessments, fall prevention, hazard communication, hearing conservation, heat and cold stress, indoor air quality, injury and illness reporting and prevention, machine shop safety, OSHA compliance assistance, personal protective equipment, respiratory protection, scaffolding, welding, and hot work. CLASSE employees and staff participate in many of these programs, some of which have CLASSE implementations with our own procedures for specific local operations. CLASSE staff and employees are expected to take responsibility for their own safety in the workplace. Supervisors and management are responsible for seeing that they have the training and tools to work safely. The laboratory directors, the CLASSE facility director, the CLASSE safety director, and the CLASSE safety committee are responsible for maintaining an environment where everyone can work safely.

Emergency planning

Emergency planning for CLASSE and the ERL are part of a campus-wide program overseen by the Cornell Emergency Management Committee and the Office of Emergency Planning and Recovery. The campus program includes physical infrastructure such as an emergency operations center, satellite phones, a campus-wide siren and PA system, automated e-mail, text and voice mail notification systems, a campus-county coordinated 911 system, and the training and drills required to use them effectively.

The program provides the organizational structure to manage and direct communications and services during an emergency. The plan identifies roles and responsibilities, emergency levels, and escalation procedures. The Cornell Emergency Management Committee, CEMC, provides oversight and coordination of activities and services to reduce risk from incidents and events, of preparedness efforts, and of after-incident reviews. The Office of Emergency Planning and Recovery provides central coordination of emergency planning and management activities, oversees development of emergency management and recovery plans, and provides staff support for the Cornell Incident Commander, the CEMC and the Emergency Operations Center. Campus units that may be required to provide essential services during an emergency include the Cornell Police, EH&S, Facilities Services, Campus Life, Gannett Health Services, University Communications, and Risk Management.

CLASSE has a formal Emergency Plan and keeps a copy in the central campus repository that is electronically accessible to first responders. The plan identifies roles and responsibilities, emergency levels, appropriate responses, and a CLASSE emergency operations center.As mentioned earlier, CLASSE has well developed explicit emergency and evacuation plans, alarm and power control infrastructure, and coordinated training for fire emergencies [2].

Environmental protection

The vision of the Environmental Compliance Unit of Cornell's EH&S is "A university culture of environmental excellence respecting Cornell's exceptional human and natural environment." In support of that vision, the unit oversees campus-wide programs to prevent spills, to review, reduce and monitor air emissions, to review and mitigate disturbance of wetlands and unique and natural areas for building sites, to ensure compliance of wastewater discharges, and to minimize the volume and contamination of stormwater runoff. It monitors several programs at CLASSE to meet these goals.

Electrical safety

The ERL will use high-power, medium-voltage electrical feeds to power many of its systems. These systems will be designed to minimize the hazards they pose. Power systems will be built to current codes, including appropriate arc-flash protection and lockout friendly hardware. De-energizing equipment, interlocks, barriers, safety procedures, personal protective equipment, and training will be used to provide a safe working environment.

All power installations will be designed in accordance with Cornell University Design Standards (2004), New York State Building code (NYSBC), National Electrical Code (NEC, NFPA70, NFPA70E), National Fire Alarm Code, Illuminating Engineering Society of North America (IES), National Fire Protection Association (NFPA), Federal Energy Policy Act of 1992 (EPACT), American National Standards Institute (ANSI), American with Disabilities Act (ADA), Institute of Electrical and Electronic Engineers (IEEE), and National Electrical Manufacturer Association (NEMA). Where the hazards are insufficiently addressed by mandatory standards, the laboratory will develop appropriately engineered safety systems and safety policies, procedures and practices. These will be drawn from the design engineering staff, local accelerator safety experience, and the prudent practices of the field. Effective barriers around magnet electrical connections will be a key component. Design and component choice will be safety friendly: convenient lockout, designed to arc-flash level 2 standards for all but primary distribution breaker buckets, which will be rated level 3. There will be a tunnel electrical crash system.

The ERL will develop lockout procedures under the Cornell University Lockout Program. Other specific procedures will be developed for special case circumstances after the technical design is complete. Training for Lockout procedures, use of high-power disconnects (arc–flash training), and other electrical procedures will be coordinated with Cornell safety training. This would include awareness training for all technical staff and procedural training for employees performing or supervising electrical work.

Fire safety

The CLASSE fire protection program is an integrated part of Cornell campus fire safety. The Fire Protection Section of EH&S supports the planning, inspection, disaster planning, prevention, training, drill, and compliance efforts of CLASSE fire safety. CLASSE writes its own fire safety plan and evacuation routes that are reviewed by the section. Inspections by the New York Office of Fire Prevention and Control and local authorities are coordinated by the Cornell Fire Marshall. Compliance plans for emergency generator testing, emergency lighting, extinguisher maintenance, and fire drills are coordinated over the entire campus. They also support the testing, maintenance, and monitoring of CLASSE fire protection systems.

Primary fire response is by the Ithaca Fire Department (IFD). Cornell provides a 24 hour-a-day emergency response team. CLASSE has its own fire marshall and fire investigation teams. In the event of a fire alarm, all three groups work together within predetermined guidelines. The authorized CLASSE personnel have special identification badges recognized by the Ithaca Fire Department. CLASSE conducts training tours for IFD and the Cornell responders. As part of the fire alarm system, there are system annunciator panels in the CESR Control Room, building entrances, and at an emergency fire response point with controls for accelerator power, building power, and building ventilation.

The fire protection systems for the new ERL are designed in accord with Cornell University Design and Construction Standards, which reference the New York Fire Prevention and Building Code, applicable parts of Factory Mutual Global and all applicable NFPA codes. The new buildings will have a combined fire standpipe/sprinkler system and will be fully furnished with sprinklers and fire hose stations. A combination of pre-action systems and wet sprinklers will be used. (Experimenter hutches and the tunnel will not have sprinklers but will be fully equipped with detectors, and visual and audible signaling devices.). The fire protection system will be monitored by the building fire alarm system and Cornell University Central Station (Barton Hall). Smoke management will be done by the building air handling system. Fire alarm strobe and horn devices will be installed in all building areas, restrooms, corridors, lobbies, large office areas, and laboratories. Pull stations will be located at all fire exits and horn/strobe devices will be located in all egress routes and exits. The current practice of having alarm enunciator panels available at entrances with emergency controls for the building power and ventilation systems will be continued at both the east and west additions and the cryogenics plant. Provision for emergency worker radio communications will also be provided throughout the interior spaces. Additional training for emergency personnel in any high-power density fire-control situations around the biggest of the compressors in the cryogenics plant will be regularly carried out by the local fire responders and EH&S much the same as they now are [3].

Biological safety

The biological safety program of Cornell's EH&S supports researchers with training, manuals, consultations, compliant waste services, and other resources. Currently the only biological experiments are by researchers from outside CHESS. Each proposal involving potential biological hazards is reviewed by the CHESS Safety Committee. Experimenter plans for hazard mitigation are reviewed and integrated with CHESS hazard management plans. A document is written for each potentially hazardous experiment that includes emergency procedures and a safety officer is assigned. Experiments with substantively new hazards may be reviewed by the CLASSE safety director or his or her designee and in some cases by the full safety committee.

Experiments have included x-ray studies of human and animal viruses, viral fragments (protein capsids), bacteria, and toxins. Most of these investigations use quantities measured in milliliters. After use, the materials are typically disinfected and disposed of through EH&S or returned to their home laboratories by the experimenters. All biological hazards are at Biohazard Level 2 or less.

The ERL will operate with the same system of pre-arrival review of biological hazards currently in place. All biological hazards will be Biohazard Level 2 or less. The facilities will meet or exceed the requirements of the CDC's *Biosafety in Microbiological and Biomedical Laboratories (5th edition)* for Biohazard Level 2. There will be written procedures prepared in advance to address inventory, safe handling and emergency response.

Chemical safety and hazardous materials

CLASSE participates fully in the programs in chemical safety and hazardous waste management overseen by Cornell's EH&S. The department maintains a chemical hygiene program that includes a laboratory safety manual, laboratory safety and chemical right-to-know training programs, a laboratory signage and labeling program, laboratory design assistance, and a laboratory inspection program. CLASSE staff working with chemicals receive the appropriate training through the University and specific individual training from knowledgeable CLASSE staff if their work assignment requires it. EH&S also works with researchers in new technologies or areas of research to identify outside resources for training and standards such as in nanotechnology. In addition, the department oversees a campus-wide chemical recycling program.

Plans to use hazardous chemicals and materials with the potential to harm employees or experimenters and proposed mitigations are reviewed by the CLASSE safety director before use. Those which differ significantly from routine use or with significant potential for harm may be referred to an expert, a special committee or the CLASSE Safety Committee for additional review. CHESS proposals utilizing hazardous materials and chemicals are reviewed in advance of running and appropriate mitigations and are procedures worked out prior to scheduling of beam time. CLASSE hazardous wastes are handled within the context of a campus-wide program to manage wastes safely and responsibly. EH&S operates the campus program that complies with EPA and NYS Department of Conservation requirements and provides support to CLASSE staff. The department provides pickups for chemical, biological, radiological and regulated medical wastes, storage of chemical wastes for up to 90 days in a central facility, and compliant disposal services from licensed contractors.

CLASSE staff responsible for hazardous waste handling and storage receive training from EH&S and outside trainers. They manage a small satellite storage area and a 90-day waste storage site at the laboratory, provide facility- and procedure-specific training for all staff working with hazardous chemicals (in addition to Cornell-required and administered training), and write and review hazardous chemical procedures.

CLASSE maintains readily available oil-spill kits and chemical spill kits near locations where substantial quantities of oil or chemicals are stored or used, and staff members are trained in their proper use. [4, 5]

Cryogenic safety

The superconducting RF cryomodules in the Linac tunnel require liquid helium at sub-atmospheric pressures. To provide cooling to such a large facility requires a large helium refrigeration plant, a distribution system for the helium, and a helium reservoir in each cryogenic device.

Because of the ability of liquid cryogens to displace large volumes of air when warmed, their use in an accelerator tunnel must be implemented with great care. The most important precaution is the minimal inventory of helium designed into the cryomodule–about 168 liters per cryomodule. The helium gas evolved is recirculated back to the compressor in a low impedance helium gas return line. Both the supply and return lines are contained within the cryomodule and are not exposed to possible damage along their length. No liquid nitrogen is used in the tunnels. Tunnel ventilation maintains an air speed of 400 feet per minute.

Most events that might result in rapid evaporation of a cryogen will cause exhaust of the helium over-pressure through the low-impedance return line to the compressor above ground. A pressure relief there would vent helium in excess of the compressor capacity. Most quenches, simple insulating vacuum failures, simple operational errors, and warm-ups would fall in this category. Specific, highly unlikely catastrophic failures have been analyzed to test the effectiveness of the design. A catastrophic failure such as a forklift truck penetrating the side of the cryomodule and evaporating all the helium in 100 seconds would produce a pressure drop of less than one psi in the return line. A second scenario investigated was an internal rupture of a helium line into the insulating vacuum and dumping of all the liquid cryogens into the insulating vacuum (and simultaneous failure of passive venting through the return line). The maximum pressure with all the helium warming to room temperature and none escaping the cryomodules was less than 3 atmospheres gauge. An even less likely scenario would be if both the helium volume and the insulating vacuum were breached while at 4.5 K and the vent lines and the ventilation failed. Because of the limited helium inventory, loss of all of the helium contained in one of the two Linacs into its tunnel would drop the oxygen availability by about 40% at peak. While this does not satisfy OSHA standards for 8–hour occupancy, it is not enough to cause loss of consciousness, especially considering helium stratification and the certainty that anyone in the tunnel would immediately evacuate (the partial pressure of oxygen even immediately after such an event would still be higher than that on Pike's Peak). These measures are in addition to the active or passive operational controls that serve to limit quench conditions and over-pressures.

The cryogenic workers and staff will have appropriate training and personal protective equipment for handling cryogens within the cryogenics plant. They will also need arc-flash hazard training and Personal Protection Equipment (PPE) for operating the electrical disconnects and breakers for the large compressors in the plant. Noise minimization will be part of the plant design, and appropriate noise protection training and PPE will be provided.

Non-ionizing radiation

Laser safety Powerful lasers are used to produce the ERL's high-quality electron beams. Lasers are also a valuable tool in many of the experiments at the ERL. All laser use will be conducted in compliance with the Cornell Laser Safety Program and in compliance with the current version of ANSI standard Z136.1. Engineering design will be used to minimize hazards. Procedural controls and personal protective equipment and appropriate training will be used to provide a safe working environment. Within the Cornell Laser Safety Program, the Laboratory has its own laser safety officer and procedures.

High-power radio-frequency radiation High-power radio frequency energy is used to accelerate the electrons in the ERL. It is generated in the immediate vicinity of the cavities that use it. The microwaves travel in enclosed waveguides from the generator to the load that are inspected and tested for leakage after assembly. The RF power systems for the main Linacs are located in the tunnel near their cavities and will be interlocked to the access control system so cavities cannot be powered when personnel are in the tunnel.

Ionizing radiation

Cornell is licensed by the New York State Department of Health, by authority of 10NYCRR, Part 16, to operate radiation-producing devices on the Cornell campus such as the Energy Recovery Linac. The University Radiation Safety Committee and the Cornell radiation safety officer prepare and enforce campus rules that implement these regulations. Radiological monitoring of the ERL is done by the staff of CLASSE and reviewed by Cornell's EH&S. The laboratory's radiation safety program is administered by laboratory staff, including a CLASSE radiation safety officer, and is reviewed by the CLASSE Safety Committee.

Cornell has an aggressive ALARA (As Low As Reasonably Achievable) program that seeks to minimize exposures to occupational workers (with an investigation trigger of one-tenth the whole-body dose allowed under federal and state regulations). The radiation badges worn by CLASSE personnel at the existing ERL Prototype and CESR facility show exposures much lower than ALARA levels and nearly all are less than the dose limits for the general public ($<$ 100 mrem/year). The practices now in place at Wilson Lab will be extended to the ERL.

The sources of radiation from the ERL are synchrotron x-rays formed in the insertion devices and bending magnets and electromagnetic shower products, such as gammas and neutrons, from particles lost from the beam. A system of shielding, gates, and light beams isolate the high radiation areas from the rest of the facility. Entry can only be made by a system of access keys which either disable all or parts of the accelerator or enable local area monitor trip circuits (depending on the location of the particular area). Keys can only be released by the ERL operator. Electronic radiation monitors are placed near the shielding around the accessible perimeter of the ERL. Neutron and gamma levels are continually recorded by a computer. Interlocks in each monitor trip the accelerator or injector if either level exceeds a threshold (usually 2 mrem/hr.) Inspection of ERL prototype monitor history shows average rates are much less than the trip levels. Operational loss monitors are used to control losses inside the radiation enclosure from unexpected sources and circumstances. Radiation survey badges are also placed around the building to monitor integrated doses near the accelerator. Personnel will wear radiation monitoring badges in monitored areas. A dedicated, self-checking fast local loss monitor system is being considered in addition to the two systems previously mentioned. To comply with the New York State acceptable dose for the general public, all of the radiation levels from outside the controlled access areas are designed to be less than 2 mrem in one hour and less than 100 mrem/year.

Cornell requires extensive training and certification of operators to responsibly maintain control and safe operation of the accelerator at all times. CLASSE provides this training and extensive additional safety training in related activities as well as substantial on-the-job and shadowing experience.

During the conversion of the present CESR ring to part of the ERL, the accelerator will be off and the only exposure of workers will be from residual radioactivity in accelerator components and the walls of the accelerator. These levels are monitored every time the weekly maintenance on the accelerator is done. There are usually only 1 or 2 places around the accelerator that have activity beyond what would be acceptable in a public place. These are marked with a sign. Lab workers would get little or no radiation exposure. Construction and tunneling workers will get no exposure since operations will have ended before they are working near the current accelerator.

The extensive operating experience from the existing 5.3 GeV CESR facility (since 1979) and the ERL prototype together with Cornell's extensive EH&S resources will be applied to the proposed ERL.

4.6.3 Construction safety

Cornell has extensive experience in managing construction of major structures on campus. Recently completed projects include: the Physical Sciences Building ($140M, 197,000 gross square feet (gsf)); Animal Health Diagnostic Center ($80.5M, 124,000 gsf); and Weil Hall

($157M, 265,000 gsf). Cornell Facilities Services, Capital Projects and Planning, typically provides a team of experienced managers, including one or more project managers, one or more construction managers, a project coordinator, and a quality control manager. These staff are supplemented where appropriate with additional Cornell University Facilities Services employees. The Cornell construction management team will provide weekly reports to the principal investigator and his/her management team. The ERL requires significant underground work. In addition to the conventional safety issues, there are many highly specialized considerations. Construction and safety oversight will be performed by a dedicated team of underground construction experts independent of the contractors actually performing the work.

Contractors are required to provide a health and safety plan with flow-down to subcontractors. Typical for major construction, the Contractor Health and Safety Guidelines for the Physical Sciences Building required the following:

- Prime contractor and on–site safety representative at all times
- All levels of tier subcontractors must submit one week prior to starting work:
  - Company's general safety policy
  - Hazard communication data including company policy, project specific material inventory, and applicable MSDS information
  - List of First Aid/CPR trained employees with expiration dates
  - Fit for duty letter
  - Documentation on training for all applicable operations
  - Lead program–if applicable.
  - Radiation program–if applicable.
  - Confined space program–if applicable.
- A one- to two- hour-long safety orientation is required for all trade persons before starting work
- Strict policies for any safety violations
- Definition for PPE including fall protection
- Policies and procedures for all types of work on project
- Emergency procedures
- Map clearly marking work areas and specific functions such as fire department access, delivery access, siltation basin, nearby pedestrian paths, protected trees and plants, etc.

Beyond construction management services, Cornell's EH&S is available to provide specialized advice and review of chemical, mechanical, radiological, and oxygen deficiency issues. Cornell's excellent track record in construction management and safety will be a critical asset in the construction of the ERL.

4.6.4 Radiological considerations for the ERL

During ERL operations, we will use the same tools to protect workers and our neighbors from radiation that have worked successfully in the past. Most of the new accelerator will be buried under more than 40 feet of earth. The new user facility will be shielded from the accelerator by thick walls of heavy-concrete. Most of the beam losses will be captured in collimators, deep underground and far from people. The x-ray beamlines for experimenters will be shielded by lead-lined walls with interlocked doors. The entrances to the accelerator will be protected by lights and signs, gates, and light beams interlocked to the accelerator.

The ERL is a new generation of accelerator. Its high-current CW beams with very small phase space will create substantial beam loss from intra-beam scattering (IBS). These losses must be taken into account in design of optics and shielding so they do not create a personnel radiation hazard, activate parts of the accelerator, or induce radiation damage in key components. Mis-tuning or component failure can cause high local losses potentially causing equipment damage or personnel hazard. Finally disposing of the beam, even with only a small fraction of its operational energy, raises challenges.

Different parts of the accelerator have very different personnel, environmental, and equipment radiation protection needs. Most of the accelerator is deep under ground and presents little hazard to people when operating. For the operational reasons mentioned above, radiation losses must be controlled even in those areas.

Since IBS is the primary mechanism of beam loss, simulations of the accelerator are used to identify the locations where most lost electrons strike the vacuum chamber walls. Different focusing patterns of the magnetic optics of the ERL that minimize the IBS and concentrate the losses at specific points around the accelerator are designed and evaluated. We will place collimators at those locations to catch these 'lost' electrons in a controlled way and dissipate their energy harmlessly. The inner part of the collimator is very close to the beam and intercepts particles outside the main beam. It is made of aluminum to minimize the production of long-lived isotopes. The outer part is large enough to absorb most of the radiation resulting from the intercepted beam, minimize water and air activation, and shield accelerator staff from residual radioactivity.The user areas have the challenges of close proximity to people, of the small apertures of the insertion devices, and of separating x-rays from high-energy bremsstrahlung gammas. Collimators to protect the experimental areas intercept lost electrons upstream of the undulators that generate the experimenters' x-ray beams. They are sized to absorb the radiation from those electrons. A thick, heavy-concrete wall provides additional protection from radiation coming from the accelerator.

There are two places where the electron beams are not deep in the earth and have the potential for creating radiation that goes up into the air and scatters back on our neighbors; this is called 'skyshine' . One location is the east section of the new experimental hall where the beams are near the surface. Here there are offices and work spaces above the beams; we will be shielding these areas to radiation levels far below those that would cause skyshine. The beam also passes through the current Wilson Lab for use by experimenters before re-entering the tunnel. Beam losses will be low compared to previous uses of the experimental hall, and heavy concrete shielding will be used to achieve acceptable levels outside of the accelerator enclosure. Another concern is the activation of accelerator components, soil, and water by the stray radiation from the accelerator. The most intense beam losses and highest potential for activation are near the collimators and the beam stop. These will contain most of the radiation within their shielding. The inner parts of both will become radioactive; the radiation from those radioactive parts will also be absorbed in the surrounding shielding. Their shielding will be sized to limit activation of the adjoining earth and ground water. Grout used to stabilize earth near the tunnel will also serve to limit groundwater proximity to the accelerator. One additional concern is activation of the cooling water required in the beam stop. This water will be recirculated locally, allowing most radioactive elements to decay in place, hydrogen gas to be safely extracted and a small fraction to be recirculated into the main cooling water within water safety standards. A similar technique is used for CESR's present positron target.

References

[1] *Cornell University Policy Library* (Current). See http://www.dfa.cornell.edu/dfa/treasurer/policyoffice/ for specific policies.

[2] *Cornell University Plan CLASSE-101: CLASSE Emergency Preparedness Plans (available upon request)*.

[3] ARUP. *Energy Recovery Project Definition Design, Volume I Report*. Technical report (2010).

[4] *Cornell University Hazardous Waste Manual* (2010). http://www.ehs.cornell.edu/docs/Hazmat/Hazardous_Waste_manual.pdf.

[5] *CLASSE Safety Handbook (manual provided to all lab employees)* (2011).