Report

of the

Fermilab Committee for Site Studies

SUBMITTED: JULY 1, 2001

with

Introduction by Michael Witherell, Fermilab Director

Contributors:

R. Atkinson	E. Crumpley
T. Dombeck	D. Finley
B. Forter	S. Geer
B. Griffing	S. Holmes
N. Holtkamp	J. Jackson
L. Koskinen	V. Kuchler
C. Laughton	P. Limon
E. Malamud	M. May
P. Metelmann	D. Nevin
R. Ortgiesen	M. Perricone
G. Robertson	S. Thompson
J. Sims	A. Tollestrup
F. Ullrich	

The community of elementary particle physicists in the United States is now considering the program for the field for the next twenty years. Every U.S. planning panel convened over the last five years has reaffirmed that the U.S. should continue pursuit of the most compelling problems in elementary particle physics, in collaboration with the international physics community, at accelerators in the U.S. as well as abroad.

Consideration of future large accelerator facilities in the U.S. inevitably focuses on sites in the vicinity of Fermilab, because Fermilab is large enough and strong enough to provide the base of talented manpower and infrastructure needed for construction and operation of a large facility. The geology of the surrounding area appears to be at least as favorable for a large accelerator project as at any of the existing major laboratories worldwide. And finally, although many new accelerators being considered would have to extend beyond the present site, there are no geographical barriers precluding such an extension.

Because of the importance of these issues to planning the future for U.S. High-Energy Physics, I formed a Fermilab Committee for Site Studies for the purpose of exploring issues and opportunities associated with the construction of future facilities on or in close proximity to the Fermilab site. This report presents the work of this committee, and represents a significant initial step in a realistic planning process for future facilities at Fermilab.

Michael S. Witherell
Director
Fermi National Accelerator Laboratory

CHAPTER 1. INTRODUCTION

"Fermi National Accelerator Laboratory advances the understanding of the fundamental nature of matter and energy by providing leadership and resources for qualified researchers to conduct basic research at the frontiers of high energy physics and related disciplines." – Fermilab Mission Statement

In support of its mission, Fermilab operates the Tevatron—the highest energy particle accelerator in the world. Since its commissioning in 1983, the Tevatron has provided insight into the deepest questions regarding the structure of matter and energy.

The Large Hadron Collider (LHC), an accelerator with seven times the energy of the Tevatron, is now under construction at CERN, the European Particle Physics Laboratory in Geneva, Switzerland. In 2006-2007, the initial operations of the LHC will relocate the energy frontier from Fermilab to CERN, signaling the end of the unique forefront role occupied by the Tevatron for two decades.

Both the U.S. and Fermilab high-energy physics communities aspire to the construction of a new forefront facility, to begin operations sometime after the LHC comes online. The currently under consideration options include:

- A first-of-its-kind muon storage ring as a high-intensity source for high-energy neutrinos;
- A second-generation electron-positron linear collider to make precision measurements of LHC discoveries;
- A fifth-generation hadron (proton-proton) collider that will exceed the energy of the LHC by a factor of three, and eventually by a factor of 15.

Fermilab has begun efforts on each of these possible machines with the conviction that Fermilab would serve as an excellent host to any of these facilities.

This report outlines both the constraints and opportunities associated with constructing any of these facilities on, or close to, the existing Fermilab site, beginning in the next decade or so.

1.1 Goals of the Study

Any machine built at Fermilab would involve common aspects, including tunneling techniques; enclosure construction; utility support; component handling and installation; environmental impacts and public acceptance and support. This study identifies these common elements and explores new ideas in these areas.

In addition to identifying the common elements of individual projects, this study also strives to characterize the Fermilab site and surrounding areas, noting advantages and limitations with respect to possible accelerator facilities. We review and evaluate the existing infrastructure and utility availability; physical and environmental limitations of the current laboratory; opportunities for extension of facilities beyond the existing site; and availability of laboratory resources and support.

1.2 Organization of the Study

The Fermilab Committee for Site Studies (FCSS) was convened in the fall of 1999, under the auspices of the Associate Director for Accelerators and the Associate Director for Operations Support, to achieve the above-cited goals and to prepare this report. The committee is chaired by the Deputy Head of the Fermilab Facilities Engineering Services Section, and includes within its membership the Head of the Facilities Engineering Services Section; the Head of the Fermilab Office of

Public Affairs; the Head of the Fermilab Environment, Safety, and Health Section; representatives from each of the projects currently being explored (the Linear Collider, the Very Large Hadron Collider, and the Muon Collider/Neutrino Source), and experts on various specific aspects of the committee's work. Specific areas of expertise include tunneling; geology; conventional construction; environmental issues; installation and maintenance; utility support, and community relations.

The committee operates under a charter included in Appendix A of this report. The charter identifies these specific charges for the committee:

- Identifying common elements and suggested approaches in all currently identified potential new projects, with a focus on tunneling, enclosures, and infrastructure.
- Identifying external interests that will be affected by plans for future Fermilab facilities, both onsite and beyond the existing Fermilab boundaries, as well as planning for the appropriate timing and means of communication with potentially affected parties.
- Characterizing the Fermilab site and the surrounding areas with respect to potential new accelerators, and exploring both the advantages and limitations of possible specific facility layouts.
- Identifying the existing infrastructure, both on the Fermilab site and in the surrounding area, and its potential application to a new facility.
- Documenting the work of the committee in summary form by the end of September 2001.

The work of the committee was executed through four subcommittees: the Design, Construction, and Geological Investigations Subcommittee; the Infrastructure Support Subcommittee; the Environment, Safety, and Health Subcommittee, and the Information Coordination and Communications Subcommittee. These subcommittees pursued their own research and sought expert advice both from inside and outside the Fermilab staff. The full committee met biweekly to coordinate the subcommittees' work.

1.3 The Study Area

The FCSS limited the geographical extent of the study to make its work feasible. Figure 1 shows the study area defined for this report. This area encompasses most of northeastern Illinois, and was defined by the following considerations:

- Proximity to Fermilab. We believe the logistics and economics of building a new accelerator facility for high-energy physics in the United States require its location on, or close to, an existing laboratory site.
- Confinement within the State of Illinois. At this stage, the FCSS chose not to deal with the complications of gathering data from multiple states. Nor did we address facilities that extended under Lake Michigan.

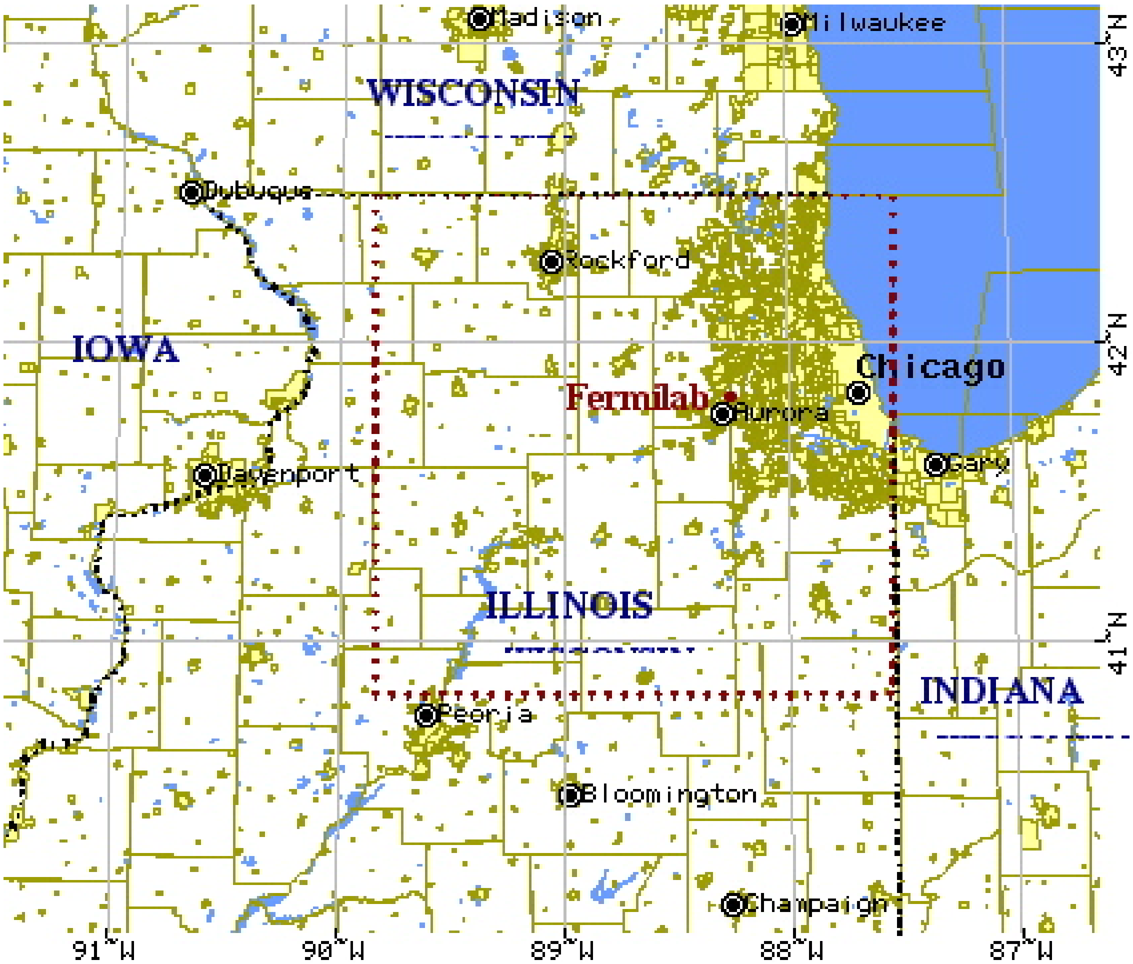


Figure 1: The study area. Fermilab is indicated by the red dot. The study area is encompassed by the red dotted line.

The geographical requirements of the three sorts of facilities studied vary greatly:

- A muon storage ring could be accommodated entirely within the existing Fermilab site.
- An electron-positron linear collider would occupy an extent of approximately 30 km in length and perhaps 100 m in width; the footprint of a linear collider is a straight line.
- A very large hadron collider would occupy a circular footprint anywhere between 100 and 250 km in circumference, with a width of perhaps 100 m. As a practical matter, the choice of the study area identifies only a hadron collider that is the subject of a recent design study, 233 km in circumference.

In all cases, we assumed that the facility would be constructed underground and that surface presence would need to be minimized. The depth could range anywhere between 30 and 800 ft below grade. The study area contains a variable geology that will affect the construction method and favor certain construction methodologies for certain sitings. These considerations are discussed in Chapter 2.

Figure 1 shows that the demographics of the study area also vary widely, covering the entire range of urban, suburban and rural locales. Ultimately, the options for a new facility will depend as much upon the surface use, the surface presence and the attitudes of the surrounding communities as it will upon the geology. Chapter 5 discusses local demographics and community attitudes.

1.4 Overview of Future Facilities Under Consideration

Three facilities are considered in this report as candidates for future construction on or near the Fermilab site: an electron-positron linear collider, a muon-storage-ring-based "neutrino factory", and a very large hadron collider. Figures 2-4 are schematic layouts of the three facilities.

Electron-Positron Linear Collider

We envisioned the electron-positron linear collider as providing collisions between electrons and positrons initially at a center-of-mass energy of 500 GeV, with some provision for upgrading, and with a luminosity in the range $5\text{-}20\times10^{33}cm^{-2}sec^{-1}$. Such a facility is already under study, with significant accompanying R&D programs, in the U.S., in Europe, and in Japan, based on different underlying technologies. The description contained in this report is based on the design being pursued within the United States, carrying the designation the Next Linear Collider (NLC). However, most of the commentary in this report is independent of the choice of technology. The specific configuration of the NLC discussed in this report is the year 2000, "CDR0.4", configuration. Future releases of this report will address modifications incorporated within the year 2001 configuration. Those modifications are unlikely to materially affect the description of the facility or conclusions related to its construction.

Figure 2 shows the NLC as an approximately 30-km facility running in a straight line. The primary features of the facility are:

- an injector complex used to prepare the electron and positron beams for injection into the main accelerating linacs;
- the main linacs, with their associated enclosures and services, extending over a 10-20 km distance; and
- the interaction area/detector enclosure, occupying an additional 5-10 km distance.

This report analyzes two representative site layouts. The first is a north-south orientation, intersecting the Fermilab site and situated in a hard-rock tunnel in the Galena-Platteville dolomite layer at a depth of approximately 450 feet. Such a facility would situate nearly all utilities off-site. The second layout is oriented in an east-west direction, approximately 30 miles west of the Fermilab site. The linac would reside in a shallow tunnel (20 ft. to 100 ft. below the surface) situated in alluvial soils. Surface buildings would be required to house equipment supporting operations of the linac in its underground enclosure. However, the population density in the immediate vicinity of Fermilab appears to argue against of a north-south configuration intersecting the Fermilab site. The rural nature of the area starting approximately fifteen miles west of Fermilab, and the existence of a power transmission corridor running for tens of miles in a straight line, would favor the east-west layout.

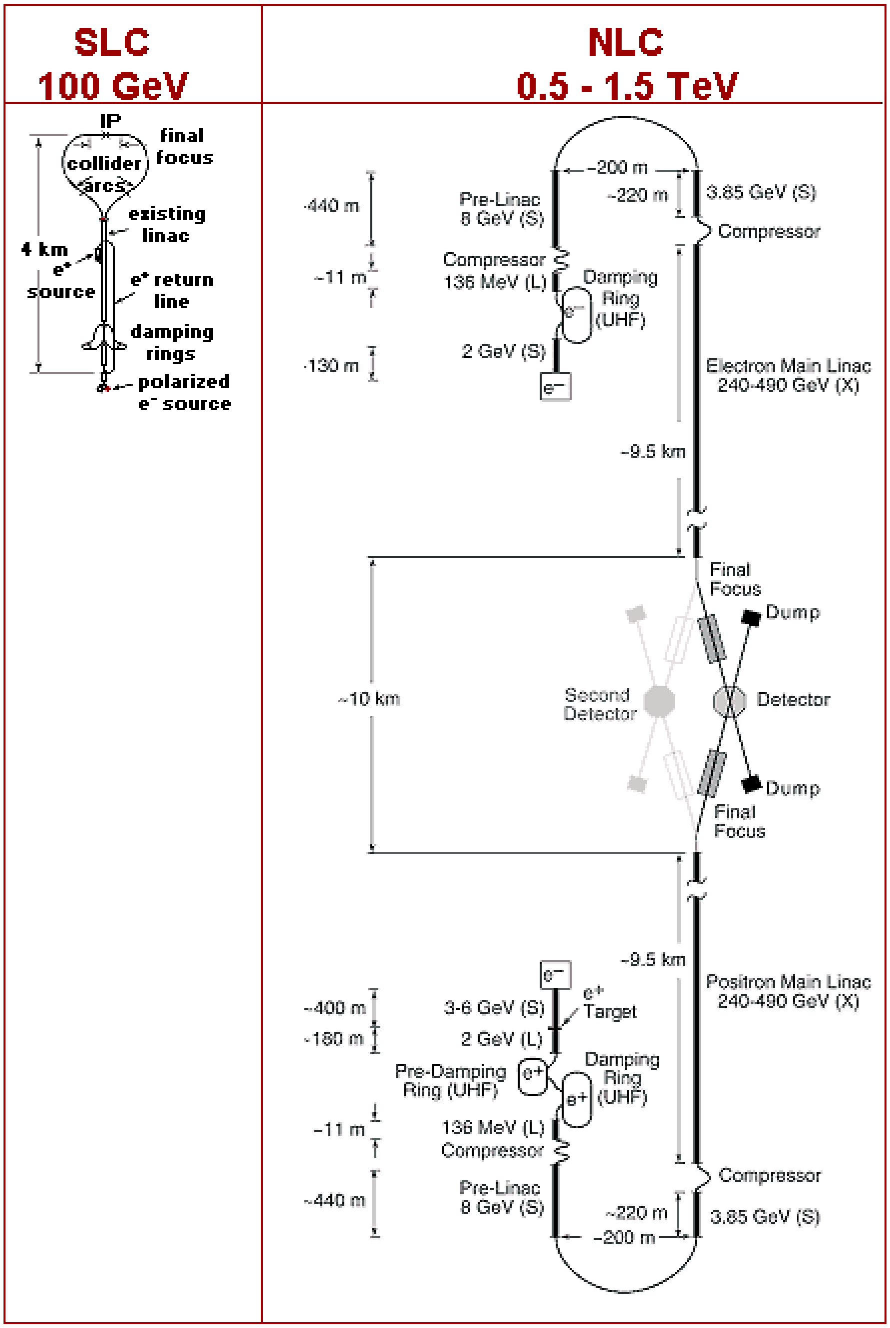


Figure 2: Schematic layout of an electron-proton linear collider. This configuration is the 2000 "CDR0.4" configuration of the Next Linear Collider (NLC). For comparison the size of the existing SLAC Linear Collider (SLC) is shown in the upper left hand corner.

Muon Storage Ring/Neutrino Factory

The "Neutrino Factory" is a novel facility based on a muon storage ring. Neutrinos generated by the decays of muons in the storage ring would be aimed at detectors hundreds to thousands of kilometers away. No such muon storage facility has ever been built, and a number of technology challenges must be surmounted before one could be built. A muon storage ring operating in the range of 20-50 GeV, with at least 10^{20} muon decays per year, would provide a very powerful platform for investigating the role of neutrinos in our universe. Again, studies of such a facility are underway in the U.S., in Europe and in Japan based on different underlying technologies. The description contained in this report is based on the “Feasibility Study of a Neutrino Source Based on a Muon Storage Ring,” released by Fermilab in the Spring of 2000. This study is currently undergoing a first iteration based on siting at Brookhaven National Laboratory. However, as in the case of the linear collider, the general features and requirements for the facility are very similar in all instances.

Figure 3 shows the Neutrino Factory in a schematic view as it is described in the Fermilab feasibility study. The footprint of the facility is approximately 1.8 km by 200 meters—small compared to the dimensions of the Fermilab site. The primary features of the Neutrino Factory are:

- a muon source consisting of a very-high-power proton synchrotron; targeting; and collection system;
- an ionization cooling system;
- an acceleration system;
- a storage ring.

The storage ring is novel in two ways. First, it would require extremely long straight sections, aimed at a remote neutrino detector, to maximize the number of decaying muons. Second, it would be inclined at a relatively steep angle—the angle and orientation being determined by the siting of the remote detector.

This Neutrino Factory configuration described in this report is completely contained within the Fermilab site boundary. The neutrino beam leaves the site, traveling through the earth in one direction and rising through the atmosphere in the other. The specific siting within Fermilab is dictated by the direction of the remote detector and by the desire to maximize the use of existing facilities and infrastructure. For this report, we have chosen a theoretical site for the remote neutrino detector in the San Francisco area, implying an east-west orientation of the muon storage ring and an inclination of 13^{o}. A consequence of this orientation is that the western edge of the storage ring is approximately 600 feet lower than the eastern edge. With the exception of the storage ring, all facilities in the Neutrino Factory are “near surface.” The storage ring itself extends from near the surface through the Galena-Platteville dolomite layer.

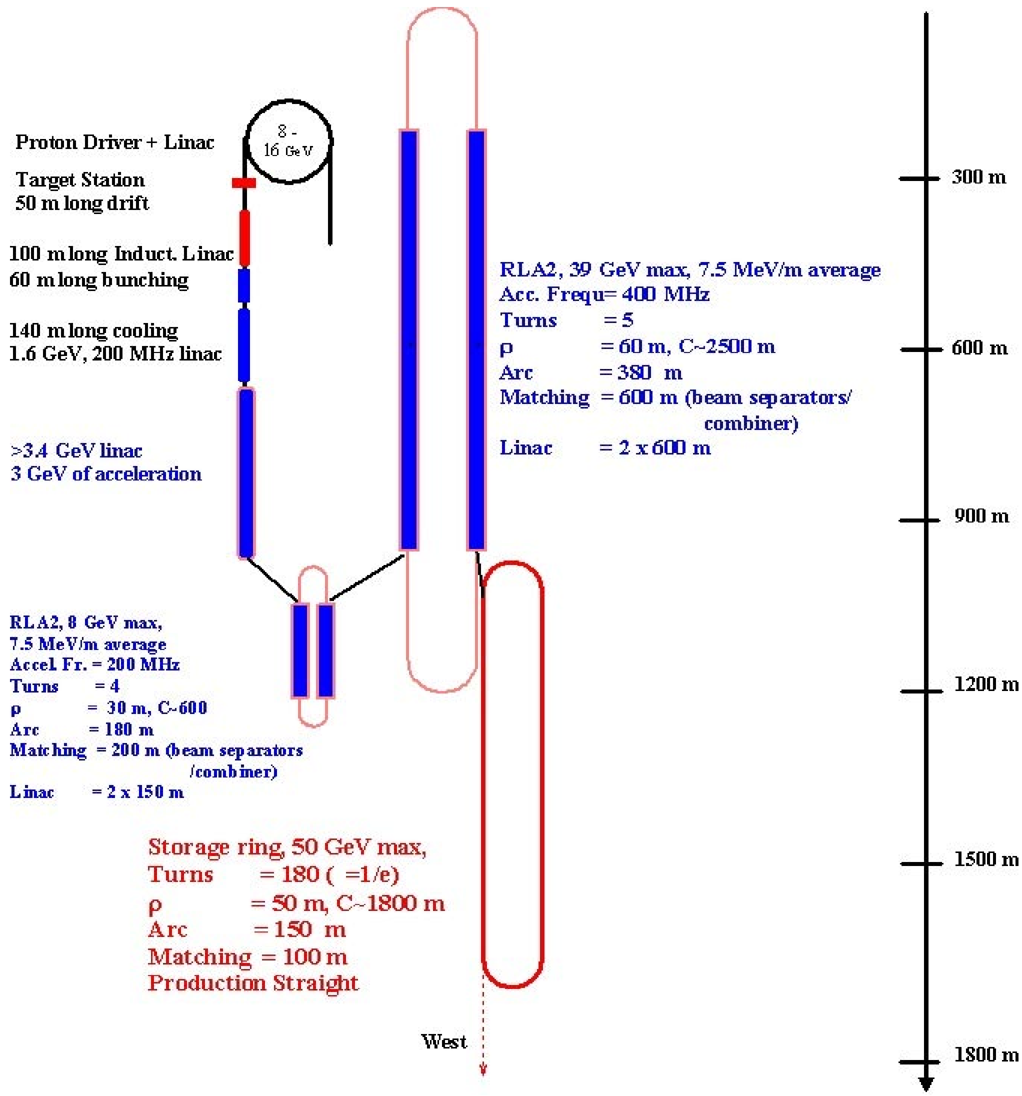


Figure 3: Schematic layout of a muon-storage-ring based "Neutrino Factory". This particular configuration is taken from the spring 2000 Fermilab "Feasibility Study of a Neutrino Source Based on a Muon Storage Ring" and is oriented to direct a neutrino beam towards a detector based in northern California.

Very Large Hadron Collider

We envisioned the Very Large Hadron Collider (VLHC) as a proton-proton collider representing the next step beyond the LHC. The VLHC is a staged collider in a large-circumference tunnel, presently envisioned as 233 km. The first stage uses simple superferric magnets to reach a center-of-mass energy of 40 TeV and a luminosity of at least 10^{34} $cm^{-2}s^{-1}$. Those rings would later become the injectors into a 200 TeV collider with a luminosity greater than $2x10^{34}$ $cm^{-2}s^{-1}$ that uses higher-field magnets in the same tunnel. Studies of such a facility are under way almost exclusively in the U.S. and assume Fermilab as the host site because of the unique existing injector facility, the flat terrain and good geology, and the expertise of the laboratory. The description contained in this report is based on a design study undertaken at Fermilab in the spring of 2001. This study assumes a staged approach to the VLHC, with a 40 TeV capability in stage one and 200 TeV in stage two.

Figure 4 shows a schematic of the VLHC, including its Fermilab-based injector. The VLHC ring is a circle, but with a circumference of 233 km it cannot be shown in its entirety at this scale. The primary features of the VLHC facility are:

- an injector complex, based on the existing Fermilab accelerators, to prepare the proton beams for injection into the VLHC ring;
- the VLHC ring;
- the interaction areas.

We discuss several representative sites in this report, all based upon a deep (300'-500') hard-rock tunnel connected to the injector complex on the Fermilab site. The preferred VLHC layout would follow the Galena-Platteville dolomite layer referred to earlier. However, several significant factors would affect the siting of a ring this large, including the impact of the varying geology on construction and operation; and the level of acceptance by local residents of both the ring and its required surface support buildings. These factors preclude identifying of a site at this time. This report provides an initial investigation of these factors and possible tradeoffs, analyzing the implications of several orientations that intersect the Fermilab site.

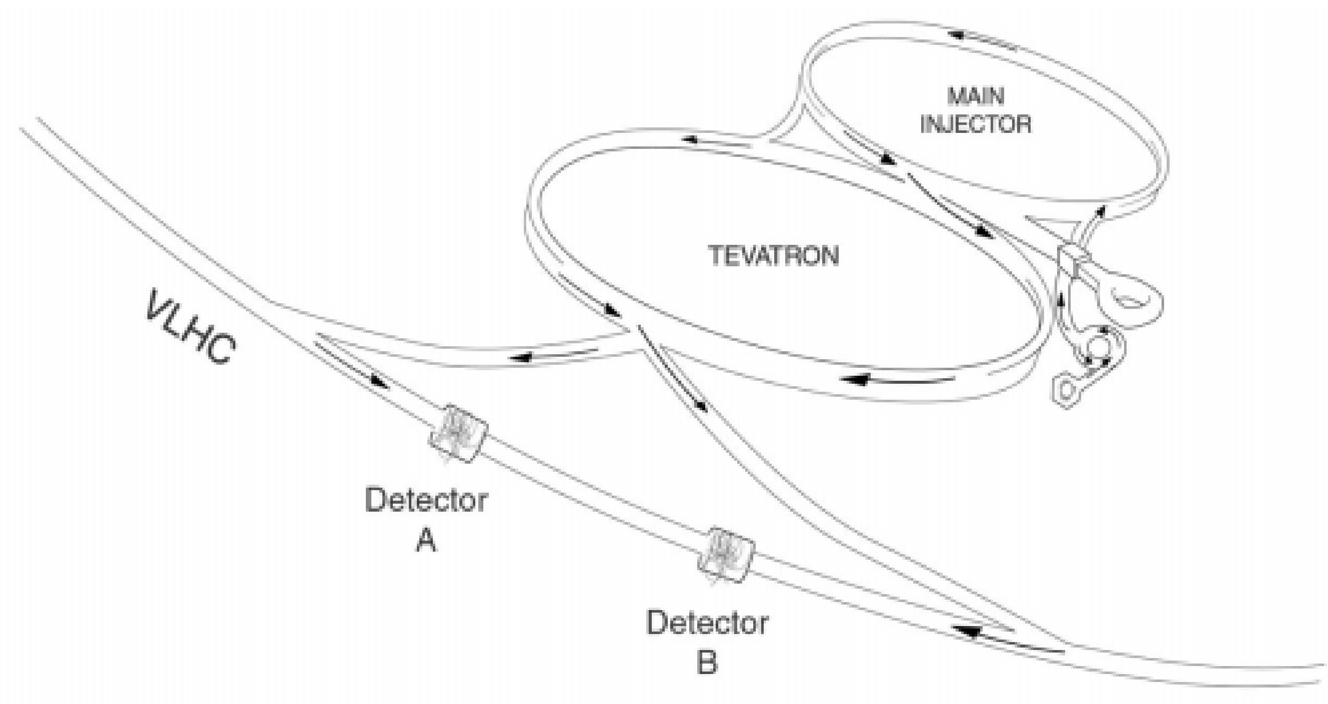


Figure 4: Schematic layout of the Fermilab-based injector complex and a segment of the Very Large Hadron Collider. This particular configuration is taken from the spring 2001 VLHC design study at Fermilab.

1.5 Structure of the Report

This report was prepared by the Fermilab Committee for Site Studies. Chapters 2-5 comprise reports from the four subcommittees. These chapters cover issues related to general characterization of the geology of northeastern Illinois, and its suitability for construction of underground enclosures; utilities infrastructure availability and requirements; potential environmental issues and regulations affecting the construction and operation of a new facility, and identification of local interested parties and an assessment of their likely attitudes toward new construction at Fermilab. Chapter 6 describes the potential layouts for each facility, and the ramifications of each layout. Chapter 6 can be read as a stand-alone unit, in place of the subcommittee reports in Chapters 2-5.

CHAPTER 2. GEOLOGY AND UNDERGROUND CONSTRUCTION METHODOLOGIES

Introduction: This chapter describes the current knowledge of the Fermilab site from a geologic and underground construction viewpoint as related to civil conventional facilities. Fermilab has established a wealth of knowledge of the site based on past and ongoing construction for high-energy physics projects. In addition, Fermilab is pursuing ongoing studies of such critical issues as ground motions, vibrations and tunnel boring machine technology. The following sections outline much of this information, with references to more detailed reports and studies.

2.1 Completed and In-Progress Project Reports

Fermilab has studied a variety of high-energy physics projects in the past 15 years, involving a range of conventional facility design parameters including geology; plan dimensions; configuration; enclosure space requirements; and surface buildings. Following is a synopsis of the approximate scope of conventional facilities for the proposed machines:

1. <u>The Illinois Proposal for the Superconducting Supercollider (SSC):</u> The SSC (circa 1985) was a new 40 TeV collider complex proposed for a Northern Illinois site near Fermilab. The proposed conventional facilities included approximately 53 miles of tunnel enclosure sited in the Galena Platteville dolomite 400 feet below the surface of Fermilab. Proposed property acquisition included 11,800 acres of acquired property, easements and right of way primarily west of the Fermilab site. The surface facilities included two main campuses and several smaller satellite buildings along the enclosure alignment. A site south of Dallas, Texas was chosen for the SSC and construction began in January 1989. The project was terminated in 1994 by the United States Congress for various reasons including budget and schedule overruns.

2. <u>Very Large Hadron Collider (VLHC):</u> The VLHC is a hadron collider currently being studied as a candidate for construction in Northern Illinois sometime after 2006. A tunnel of approximately 233 km in circumference would initially house 20 TeV rings (Stage 1), which would serve as an injector to the 100 TeV rings (Stage 2). These would initially allow collisions at 40 TeV and 200 TeV. A study and costing exercise for a 38 km 3 TeV ring was prepared in 1999. The proposed conventional facilities of this smaller machine were expected to be housed in an enclosure sited in the Galena Platteville dolomite. The Design Study for a Staged Very Large Hadron Collider was completed in May 2001. Three ring orientations were studied, not because they were favored sites (there are no favored sites as yet) but because they result in an almost complete characterization of the construction scenarios in the Fermilab area. There are two northern orientations, one flat, which samples numerous different geological strata, and one tilted to remain entirely within the Galena-Platteville dolomite. There is one southern orientation, which cuts through the Sandwich fault, stable fault that has significant geological displacements on either side. Proposed property acquisition varies depending on the alignment and machine scope.

3. <u>Linear Collider :</u> The Linear Collider experiment is an electron-positron machine currently being studied for siting at Fermilab or in Northern California in this country, or in Japan or Germany abroad. The proposed conventional facilities at Fermilab include two potential sites designated north-south and east-west. Linear enclosure tunnel lengths range from 12 to 18 miles depending on the specific configuration. Proposed property acquisition varies with alignment. The east-west solution would require as much as 3000 acres of acquired property, easements and rights of way primarily west of the Fermilab site. The north-south solution is sited at Fermilab; however, the machine footprint extends as much as four miles both north and south of the Fermilab boundaries, primarily along utility corridors and industrial/commercial developments. This solution uses most of the Fermilab campus but would require additional buildings both on and off site. Offsite land acquisition for such a machine could require between 10 and 20 acres. The east-west solution, proposed some 30 miles west of Fermilab, requires more new surface facilities than the north-south solution. As much as 3000 acres of land would be required for this solution.

4. <u>Neutrino Factory:</u> The Neutrino Factory is a facility that would develop some of the existing Fermilab machines to create muons, which eventually decay into neutrinos. The high intensity neutrinos would then be aimed through the

earth at a detector as far as a few thousand miles from the Fermilab site. The conventional facilities include six miles of tunnel enclosure sited primarily in the glacial till with only the decay region enclosures sloping into the bedrock to allow the neutrinos to be directed at a remote detector. This facility would be contained entirely on the Fermilab site, requiring no property acquisition. The surface facilities would supplement the existing Fermilab campus and add experiment-related support buildings.

2.2 Technology Studies

The next generation of accelerators at Fermilab provides an opportunity to advance the state of the art in tunnel boring technology. These innovations will benefit the tunneling industry, an industry growing in importance from environmental needs to put more infrastructure underground.

Based on local experience, a tunnel-boring machine (TBM) is the most efficient tunnel construction method in hard rock for distances over a mile. Conventional TBM equipment uses disk cutters to excavate rock. The resulting circular cross-section often requires significant modifications, including construction of a concrete flat floor system for the required workspace. A modified TBM can produce arch cross sections with semi-flat floors, with a more efficient finished section for an accelerator enclosure. The TBM is modified by mounting two horizontal drum cutters immediately behind the cutter head, creating a tunnel with an arched roof and flat floor. Such modified TBM equipment is currently used in other countries.

Equipment manufacturers are currently developing instruments to improve TBM results: pressure sensors; flow meters in the hydraulic and water systems; vibration sensors placed on all critical devices; and TV cameras positioned to watch all moving components. The TBM could theoretically be operated remotely, from any place on the construction site, with minimal personnel in the tunnel, dramatically reducing labor costs, which constitute about 40 percent of tunneling costs, and improving job safety. Maintenance can be performed as scheduled. Breakdowns are less costly, without large crews idled during repairs. If a vehicle breaks down en route, a substitute vehicle can go around the broken vehicle parked in the tunnel. The broken vehicle can be repaired in place or pulled out of the tunnel during a maintenance shift.

2.3 Surface Features

The existing surface of northern Illinois is primarily flat, with surface elevations ranging from 400 feet to 1000 feet above sea level. Much of the eastern half of northern Illinois is developed with Chicago suburban communities and municipalities, including many commercial, residential and industrial complexes. Undeveloped areas are currently used for agriculture, primarily corn and soybeans. Major water bodies include Lake Michigan located approximately 40 miles east of Fermilab, the Illinois River approximately 20 miles southeast of Fermilab and the Fox River approximately 2 miles west of Fermilab. An intricate highway system extends throughout the northeastern Illinois area.

The 6800-acre Fermilab site is also relatively flat with less than 50 feet of fall from northwest to southeast. Approximately one-third of the Fermilab site is developed with various high-energy physics accelerator complexes or related experimental areas. A system of natural and manmade ponds offers both recreational and industrial use. Many of the existing surface water ponds are used for heat rejection. Indian Creek and Kress Creek are the primary watercourses onsite. Approximately one-third of the site is leased to local farmers for agricultural uses. Another one-third of the site includes prairies, wetlands and recreational areas. A series of paved roadways exist throughout Fermilab. A land management plan below, outlines the existing land uses onsite. Refer to the Fermilab Comprehensive Land Use Plan for more detailed site information, and for land use information involving the surrounding communities.

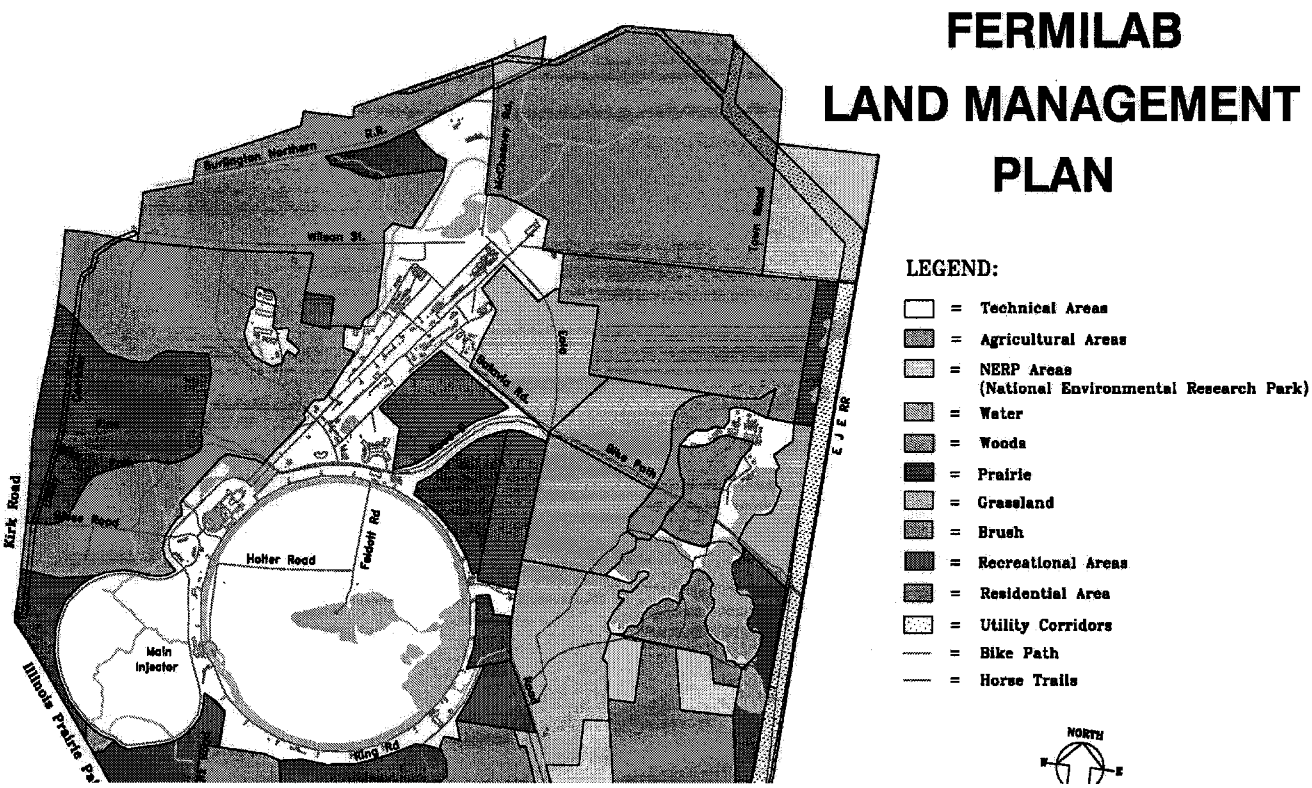


Figure 2.1 - Fermilab Land Management Plan

The Fermilab site contains over 25 miles of paved roads and more than 300 buildings. There are some 15 miles of near-surface underground enclosures used for experiments. Local earthen berming required for radiation shielding is apparent in many of these areas. The majority of the site's infrastructure has been developed in the last 35 years, since the inception of the National Accelerator Laboratory. The onsite surface development is located in five main areas: 1. Wilson Hall Footprint Area, 2. The Main Injector Ring Area, 3. The Main Ring Area, 4. The Fixed Target Area, and 5. The Village.

The Wilson Hall, Main Ring and Fixed Target areas were the first to be developed, with high-, medium-, and low-rise office and industrial building structures. The Main Injector Area is the most recent development, constructed in the early to mid 1990's. The Village Area consists primarily of residential and light industrial buildings that are a conglomeration of the buildings salvaged from the community of Weston, Illinois, purchased in the late 1960's for the development of the NAL. Below is a portion of the US Quadrangle map showing the development and topography.

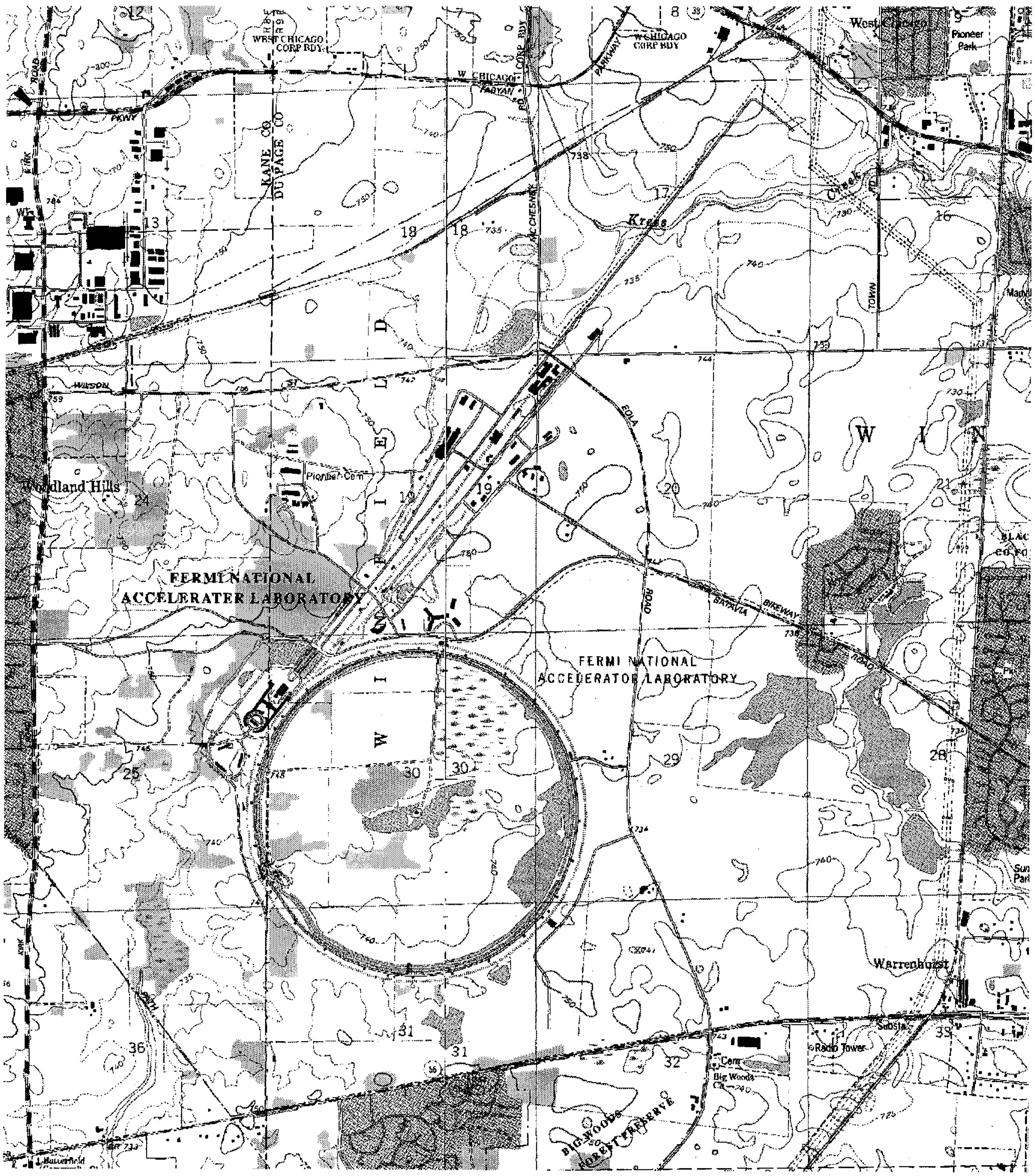


Figure 2.2 – Fermilab Development and Topography

2.4 Geologic Information

Fermilab is located in the Bloomington Ridged Plain of northeastern Illinois, a part of the Till Plains Section of the Central Lowlands physiographic province. The Bloomington Ridged Plain is a glacial landscape underlain by a sequence of Quaternary-age glacial deposits overlying Paleozoic-age bedrock. Fermilab lies primarily on an intermorainal zone east of the north-south trending Minooka Moraine and west of the similarly trending West Chicago Moraine. The northwest and extreme west regions of Fermilab also include a portion of the Minooka Moraine, an end-moraine ridge formed at the edge of one of the advances of the Woodfordian-age Lake Michigan glacial lobe. The intermorainal region features a sequence of loess, alluvial and lacustral silts and sands above unconsolidated Quaternary-age glacial tills, ranging in thickness between 60 to 100 feet, all overlying a Silurian-age massive microcrystalline dolomite bedrock approximately 150 feet thick. The Silurian dolomite then overlies the Maquoketa Formation, which consists of approximately 150 feet of Ordovician-age shale, siltstone and dolomite. Deposits below the Maquoketa consist of Ordovician-aged dolomite and limestone of the Galena Formation.

Ground Water Basin

The uppermost aquifer in the region is the Silurian-age dolomite bedrock. The overlying Quaternary-age glacial soils contain a saturated zone that is the primary avenue of recharge for the bedrock while recharge to the glacial deposits is due to local precipitation. The glacial soils contain sand and gravel lenses dispersed sporadically within and between predominantly clayey tills.

Glacial Deposits

The Quaternary deposits at Fermilab overlie bedrock in a sequence of distinctive formation, members and facies that differ in origin, physical properties and hydrogeologic characteristics. The sequence of deposits consists of a thin mantle of Peoria Silt and related deposits less than 5 feet thick overlying a succession of glacial deposits making up the Lemont Formation. The Lemont Formation is subdivided into two members, the Yorkville and Batestown Members. Stratified sediments classified as the Henry Formation can occur between the Lemont Formation members and member facies.

The Peoria Silt usually mantles the site and generally classifies as a Lean Clay (CL), under the Unified Soil Classification System (USCS). The modern soil profile is developed in the Peoria Silt. Underlying this unit is the Lemont Formation, which makes up the bulk of the Quaternary-age sequence. The UpperYorkville Member is composed primarily of clay-rich diamictons and is subdivided into three informal facies (Facies A, Facies B and Facies C). Each facies is a uniform, clay-rich diamicton deposited subglacially by a sequence of successive glacial events. Some areas are capped by a fourth, Resedimented Facies, a sequence of resedimented diamicton and associated meltwater deposits remaining when ice retreated from the Fermilab area. Each of the subglacially deposited facies consists of massive, fine-grained diamicton that classify as Lean Clay (CL). Facies A and Facies C contain scattered small dolomite clasts. Facies B contrasts with Facies A and Facies C by being clast-rich with common dolomite clasts up to 85 mm in diameter and having a coarser-grained matrix. Facies C has an extremely high clay content compared to the other two facies. The lower, Batestown Member typically overlies bedrock and is generally composed of massive, fine-grained clast-rich diamicton, but can locally include interbedded sand and silt. It classifies as Lean Clay (CL) to Sandy Lean Clay with Gravel (CL). The Henry Formation consists predominantly of stratified sand and gravel deposited in front of the glacier. It has been observed at Fermilab between Facies A and Facies B, between Facies C and the Batestown Member, and between the Batestown Member and bedrock.

Bedrock

The uppermost bedrock is Silurian-age Niagaran and Alexandrian Series dolomite approximately 150 feet thick. These units occur approximately 65-100 feet below ground surface at elevations between 635-688 feet above mean sea level, sloping to the southeast in conformance with the regional formational dip of 10 to 15 feet per mile. The bedrock is generally massive with occasional bedding plane partings and very few vugs. The Silurian-age sediments consist of three formations, in descending order: Joliet, Kankakee and Elwood. Ordovician-age Cincinnatian Series dolomites and shales underlie these. These deposits act as a confining layer for lower deposits.

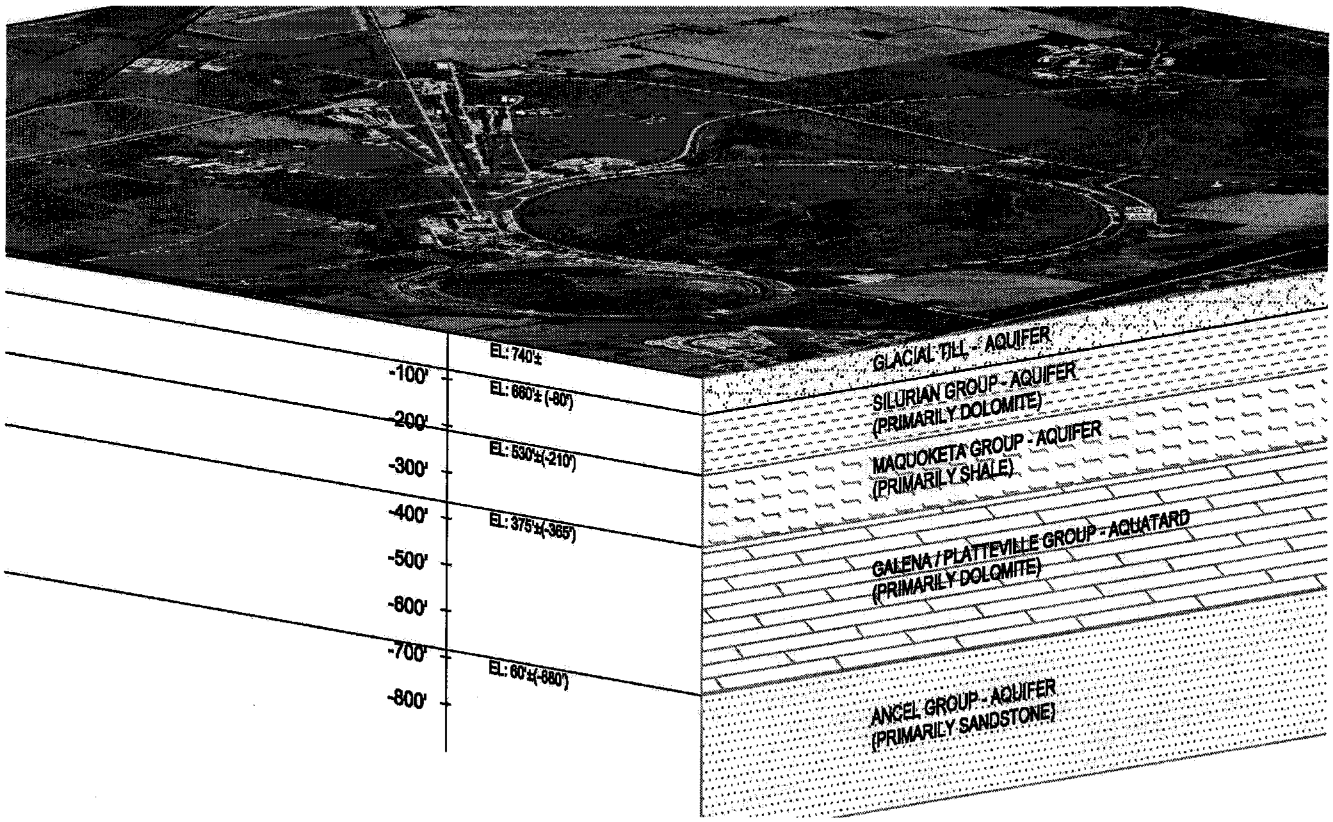


Figure 2.3 Geology at Fermilab

Hydrogeology

Types of Aquifers

Regionally, three hydrostratigraphic units (groups of geologic formations that together form aquifers or aquitards) have been identified for northern Illinois. These are the Prairie Aquigroup, Upper Bedrock and Midwest Bedrock Aquifers. The PrairieAquigroup occurs in sand and gravel units within Quaternary deposits and has not been mapped on the Fermilab site. Quaternary deposits at Fermilab essentially act as a confining unit for the Upper Bedrock aquifer.

Glacial Deposits

The Lemont Formation makes up the bulk of the Quaternary-age sequence overlying bedrock at the site. In northeastern Illinois, the Lemont Formation is composed of as many as three members; at the site, it contains the two oldest members, the Yorkville Member and underlying Batestown Member. The Yorkville Member is generally over 50 feet thick at the site and is composed primarily of clay-rich diamictons. It is subdivided into four informal but distinctive facies at the site. The uppermost facies, the Ice-Marginal Facies, is a sequence of resedimented diamicton and associated meltwater deposits left behind as ice retreated from the Fermilab area. Underlying the Ice-Marginal Facies are three massive, uniform, clay-rich diamictons interpreted to be subglacial tills deposited by successive glacial advances. These are informally referred to from the top down as Facies A, Facies B, and Facies C. The oldest member of the Lemont Formation at the Fermilab site, the Batestown Member, overlies bedrock and is typically less than five feet thick, but ranges from 1.5 to 34 feet thick. In contrast to the Yorkville Member, it is composed primarily of coarse, clast-rich diamicton and also includes discontinuous beds of sorted meltwater deposits. The combined glacial sequence affects groundwater flow; because fine-grained subglacial tills dominate the sequence, it also acts as a confining unit over the underlying Silurian-age bedrock aquifer.

Stratified sediments of sand and gravel that were deposited in proglacial settings, classified as the Henry Formation, can be present as inter-tongued lithostratigraphic sediments between the regional subglacial diamictons and above the bedrock. These deposits are coarse-grained and have the potential to be highly conductive when present as extensive horizontal units.

Horizontal and vertical gradients within and between each of the glacial units were calculated with piezometric data from nested piezometers. Horizontal and vertical hydraulic conductivities have been determined from field and laboratory analyses. Horizontal hydraulic conductivities are typically an order of magnitude greater than vertical hydraulic conductivities. Calculated vertical gradients were mainly downward for all of the units except for the water table (resedimented till). The resedimented unit exhibited an upward gradient during part of the year. The vertical gradient between the Batestown Member and the Silurian-age dolomite is very small, suggesting a hydraulic connection. The vertical gradient was much greater than horizontal gradients (by an order of magnitude) for the middle glacial stratigraphic units. Consequently, calculated vertical seepage velocities also were greater by an order of magnitude. Vertical downward flow has been determined to be the dominant flow direction within the upper and middle Quaternary deposits.

Ground water within the upper glacial deposits, Yorkville Member, has been demonstrated to be Class II ground water. This class of ground water is defined in 35 Illinois Administrative Code (IAC), Part 620. The ground water within the lower glacial deposits, Batestown Member, and Henry Formation deposits can be hydraulically connected to the bedrock and can be classified as Class I ground water.

Upper Bedrock Aquifer

The Upper Bedrock Aquifer System at Fermilab consists of the Silurian-age dolomite. It constitutes the uppermost aquifer of any consequence on the site and contains Class I ground water as defined in 35 IAC 620. The piezometric surface of the upper bedrock aquifer is generally above the upper bedrock surface and lower coarse-grained Quaternary unit, indicating that the bedrock aquifer is under a confined condition by the overlying fine-grained Quaternary deposits. Where the Batestown Member is of appreciable thickness and of a coarse-grained nature, local unconfined conditions may occur.

Within the dolomite, the ground water occurs in irregularly distributed joints, fissures, solution cavities, and other void spaces. The water-yielding openings are irregularly distributed, both vertically and horizontally. Most of the joints, however, are nearly vertical, with joint sets trending N80^{o}W and N69^{o}W. These joints contain very little filing. They are wavy and uneven as well as sound and unaltered. The upper portions of the Silurian dolomite are reported to be more permeable than the lower parts, and recharge is derived locally, mostly from vertical infiltration of precipitation through the overlying glacial deposits and lateral flow from recharge areas. Near Fermilab, ground water movement is southerly to southeasterly, following the regional formational dip. However, localized ground water flow can be toward dewatering areas.

Three non-transient, non-community production wells within the site draw from the Upper Bedrock Aquifer System. Wells W-1 (located south of Wilson Hall) and W-3 (located at the northeast corner of the intersection of Receiving Road and B Road) supply drinking water to the Main Site while well W-5 (located at the Colliding Beam Facility at D0) supplies drinking water to D0. Pumping at these locations has generated cones of depression, which have exerted strong influences on the direction of ground water flow locally. Several smaller semi-private wells also supply water to small on-site facilities and exert only slight, localized influences on ground water flow.

Midwest Bedrock Aquifer System

The Midwest Bedrock Aquifer System, overlying the Basal Aquifer Cambrian-age Eau Claire Formation, comprises three main groupings of rock formations beginning at approximately 100 feet above mean sea level. These formations are in (descending order): the Ancell Aquifer, made up of the St. Peter Sandstone and Glenwood Formations; the combined

Franconia Formation, Eminence-Potosi Formation and Prairie du Chien Group; and the Ironton and Galesville Aquifer. The shales of the overlying Ordovician-age Maquoketa Formation and Galena Platteville Group, beginning at approximately 550 feet above mean sea level, constitute a confining layer and aquitard to the downward movement of ground water, effectively isolating the underlying Cambrian-Ordovician and Mt. Simon Aquifers from any potential influence from Fermilab. Recharge to the aquifer system occurs in parts of McHenry, Boone, Kane, and DeKalb Counties where the Maquoketa Formation contains an appreciable amount of dolomite or is relatively thin or absent.

Ground Motions/Vibrations

Ground motions and vibrations pose problems for the siting and design of some high-energy physics experiments. For example, electron-positron linear colliders have stringent requirements for vertical and horizontal displacement within specific frequency ranges. Ground motions are generally low-frequency and site- specific. They include the motions induced by the movement of the earth's crust; and the activity of the surrounding community, including seismicity, railways, construction, air traffic and other sources of cultural noise. Vibrations are generally of higher frequency and include motions induced by nearby machines and equipment related to the experiment itself, such as pumps and cooling water flowing in pipes and klystrons.

The geologic strata selected to house enclosures for such a machine will have specific responses to ground motions and vibrations, further complicating the design of a collider's technical and conventional components. For example, a deep rigid stratum, such as dolomitic stone, may attenuate amplitude of a particular motion more rapidly than a glacial material; however, the higher shear wave velocity and transmicity of the rigid stone may not attenuate the frequency to a correspondingly acceptable level. On the other hand, siting of such an enclosure near the surface in glacial material yields much less homogeneous foundation materials. Variations in water tables, void content of soils and expansive properties of glacial materials expose the machine to more potential for misalignment. The siting of a collider along a road or railway right-of-way may also pose problems for maintaining sub-micron alignment tolerances. The effects of mechanical vibrations from railways should be a topic for further study, if not already explored in ongoing studies of the fixed-target area and the nearby North Aurora Quarry. At the Fermilab site, the machine could be located in a tunnel structure 100 to 450 feet below grade, the overburden consisting in large part of dolomite rock. The situation might be comparable to being located at the surface, but parallel to a road running 100 to 450 feet away from the enclosure laterally.

Earth noise, seismic noise created by the interaction with wind or sea, also poses a problem for machine design. Typically, earth noise lies in frequencies below 1 Hz, while cultural noise lies above 1 Hz. Amplitude of ground motion decreases as $1/f^2$ with increasing frequency. Seismic noise conditions may affect siting decisions: For example, a site near a shoreline might align the accelerator parallel to the shoreline and perpendicular to the motion of the waves. A plane seismic wave traveling perpendicular to the accelerator has minimal effect on machine alignment.

Devices in the accelerator tunnel also affect machine alignment. Sources of mechanical noise include power lines, cooling water pipes, and vacuum pumping systems. A siting criterion might include provision for seismic noise to be as small as sources of mechanical noise emanating from within the accelerator tunnel. It is likely, but has not been demonstrated, that surface noise generated above a 450-foot overburden will be small compared to mechanical sources from within the accelerator tunnel.

A study for the Illinois SSC proposal investigated vibrations from truck and railroad traffic, considered the largest source of cultural noise in the region. This investigation monitored truck traffic over an expansion joint of a bridge, and the passing of freight trains. Truck traffic showed displacement of 2.9 to 19.3 $^{\mu}$m on the bridge abutment. However, 65 feet down and 150 feet horizontally to a rock quarry floor, these movements were attenuated 92 to 241 times, down to a range of .03 to .08 $^{\mu}$m. The train traffic displacements in the ground next to the rail line were 1.6 to 4.06 $^{\mu}$m; at 60 feet down and 190 feet horizontally to the quarry floor, the displacements were attenuated 62 to 123 times, down to a range of .013 to .066 $^{\mu}$m. (Reference: Robert A. Bauer and David L. Gross, *Geology of the Greater Fermilab Region*, Illinois State Geological Survey)

Ongoing studies suggest technical solutions such as interferometry, beam positioning and beam-based feedback, coupled with engineering for conventional facilities including isolation and enclosure design. A consortium within the high-energy physics community is currently studying ground motions and vibrations, and their effects on accelerators. A recent seminar held at the Stanford Linear Accelerator Facility discussed these issues. More information on this subject can be found at the following URL:

http://www-Project.slac.stanford.edu/lc/wkshp/GM2000/agenda.htm

In addition, Vladmir Shiltsev of Fermilab and Andrei Seryi of SLAC have collected data on ground motions in a variety of locations around and on the Fermilab site, including the Fermilab fixed target line, and in deeper rock strata at the North Aurora Quarry. Future measurements may take place in the newly constructed NuMI target hall. **(FERMILAB-Conf-01/152 "VLHC/NLC Slow Ground Motion Studies in Illinois.")**

Summary of Geologic Information

Below and adjacent to the Fermilab site, glacial sediments overlie a bedrock sequence of limestone, shale and dolomite. Fracturing in these units is widely spaced and only one major fault (Sandwich) is present in the southwest corner of the study area.

The limestone and dolomite (dolostone) units are both favorable tunnel sites for housing accelerators. The dolostones are homogeneous, medium- to high-strength, non-abrasive rock units; they have already been extensively mined, with good results, in the Chicagoland area. With adequate provisions for rock support and grouting, circular TBM-mined tunnels can provide a relatively dry and stable environment, suitable for housing most accelerator and detector systems. If underground sites are carefully selected, caverned detector housings with excavation spans in excess of 20 meters should be readily achievable using conventional rock anchor techniques.

Decline tunnels (injection lines) and vertical shafts must be constructed to provide for beam transfer, access and utility drops. In the glacial tills, these excavations will require systematic support and treatment for ground and water control. If excavations extend into the shale units, additional support measures will be needed to ensure the long-term stability of the accelerator and detector foundations.

Ground motions and vibrations will require in-site tests to determine the site-specific responses to both cultural and machine noises. Construction of more motion-sensitive colliders should take place in the hard and competent dolomite rock underlying much of northern Illinois.

Fermilab has completed many geotechnical reports and studies over the last 30 years, with more than 1,000 soil borings. Refer to the bibliography for a listing.

2.5 Constructability and Cost Information

In the past 35 years, Fermilab has constructed many high-energy physics projects, primarily with near-surface "cut and cover" type enclosure and building construction. This experience provides Fermilab with a wealth of knowledge regarding the constructability and cost of civil conventional facilities. The ongoing NuMI project offers Fermilab the ability to understand the means and methods of deep excavations and tunneling. The following paragraphs discuss our understanding of several elements of civil conventional facilities, including: excavation in glacial materials, near-surface enclosure construction and deep tunnel construction. Costs discussed below do not include outfitting of spaces, such as installation of electrical, mechanical and technical components.

Excavation in Glacial Materials

Fermilab has constructed several miles of below-grade structural concrete enclosures, using open-cut and braced-cut construction.

Open cut excavations use scrapers or backhoe equipment. The final excavation includes stabile slopes down to the base of the excavation, which are necessary to provide a safe environment for workers. The angle of sloping excavations depends largely on soil parameters such as type, moisture content and strength and is generally 45 to 70 degrees from vertical for soils at

Fermilab (for design regulations, see OSHA 29 CFR 1926, Subpart P, "Excavation"). Linear excavations required for cut-and-cover enclosures are often made by means of a large backhoe stockpiling spoil immediately adjacent to the excavation. This type of excavation is generally only feasible at depths of less than 40 feet because the volume of excavated material and the size of the excavation become very large.

Braced excavations use structural support from vertical walls, through sheet piling, wood lagging, vertical piling or a combination thereof. Some common types of braced excavation systems include soldier pile with wood lagging, and secant wall systems. Soldier pile and wood lagging systems involve installation of vertical steel H piling on approximately six-foot centers. After all the piling is installed around the perimeter, the contractor begins to excavate within the area of the piling. Approximately every four to ten feet the contractor installs a level of wood lagging between the soldier piles to hold back the soil. Often grouting is required behind the lagging to engage the lateral forces of the excavated materials. Secant pile walls involve excavating a vertical shaft with the use of a caisson rig and filling it with steel H piles and concrete. The piles are closely spaced, allowing the shafts to overlap slightly and creating a secant (hence the name) wall of concrete piers. When the wall is in place, the contractor excavates the interior area. Secant walls have a distinct advantage over soldier pile and lag walls: their final structure is very stiff, and conducive to excavations adjacent to equipment or existing buildings that are settlement-sensitive. The primary advantages of soldier pile and lag walls lie in cost and schedule. The cost of soldier pile and lag walls is approximately 60 percent of secant walls, and they take less time to build. Secant, soldier pile and lag walls all need lateral bracing, at spacings of 5 to 20 feet. The bracing can consist of compression elements within the excavation or drilled and grouted tiebacks into the soil itself. Costs of braced excavation walls range from $30 to $100 per square foot of wall, depending on the type of construction and on the number of braces or tiebacks. These methods are generally used for excavations deeper than 40 feet, and for local excavations required for below-grade areas of enclosure service buildings and experimental areas.

Excavation costs for near-surface, open-cut construction range from $3 to $10 per cubic yard, depending on the distance required to haul the spoil for stockpiling, and on the equipment used for excavation. Backfilling costs also range from $3 to $10 per cubic yard, depending on compaction specifications and lift heights for placement. The chart below presents the approximate volume of excavations per lineal foot, for various depths of excavations.

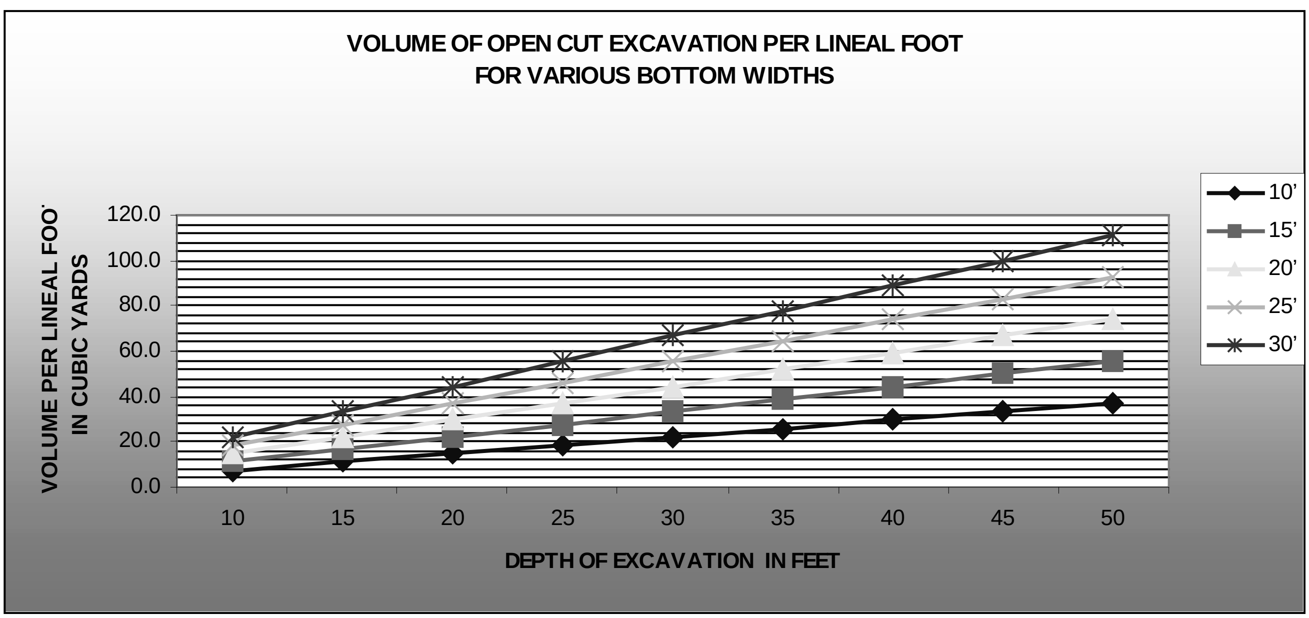


Figure 2.4 Excavation Volumes

Our experience has shown the importance of using the design phase to anticipate the means and methods for a particular excavation, as well as estimating costs. Our experience has also shown the importance of allowing the subcontractor some leeway for alternate methods of excavation, as long as they are safe. This leeway may promote a more cost-effective solution and, thus, a more attractive bid. In addition, the subcontractor may be able to modify a project schedule with a choice of means and methods.

Near-Surface Enclosure Construction

Over the past 35 years, nearly 15 miles of near-surface underground enclosures have been constructed on the Fermilab site. The underground enclosures primarily consist of arch- or rectangular-shaped structural concrete sections buried between 15 feet and 35 feet below the surface. Cross sectional dimensions of tunnel enclosures range from 8 to 12 feet high and 8 to 16 feet wide. Below-grade enclosure areas for experimental areas, such as CDF and D0, require much larger spaces.

The Main Injector Project represents the most recent project consisting primarily of near-surface enclosures. The Main Injector has approximately two miles of below-grade enclosures, 10 feet wide and 8 feet high, with 25 feet of earthen cover. Its nine service areas required larger below-grade areas. Construction of the enclosure tunnels consisted of open-cut earth excavation; laying a 4 inch mudslab base; constructing a reinforced concrete cast-in-place base; setting an inverted precast concrete u-shaped segment, and backfilling to the required depth of earthen cover. Other elements of the construction included waterproofing; aggregate backfill around the enclosure; and underdrain installation adjacent to the enclosure, to lower the hydrostatic forces induced by local perched water tables.

Fermilab has invested significant time and funding into analyzing below-grade enclosures. In the early 1980's, Fermilab investigated the effects of various backfilling techniques on buried enclosures. This report determined that future enclosures could be designed with less lateral earth pressure than most structural engineering textbooks would recommend, because of the relative flexibility of the structure and the mobilization of the soil due to the aggregate backfill around the enclosure. Recently, the laboratory has examined the relative cost effectiveness of various cross sectional dimensions of enclosures for various earthen fill heights. We have developed tools to determine the volume of concrete required for a specific enclosure cross section. Below we have included a graph of various enclosure widths for a 10-feet high enclosure at various depths. This tool assists engineers in determining the relative cost of an enclosure structure based on dimension and fill height.

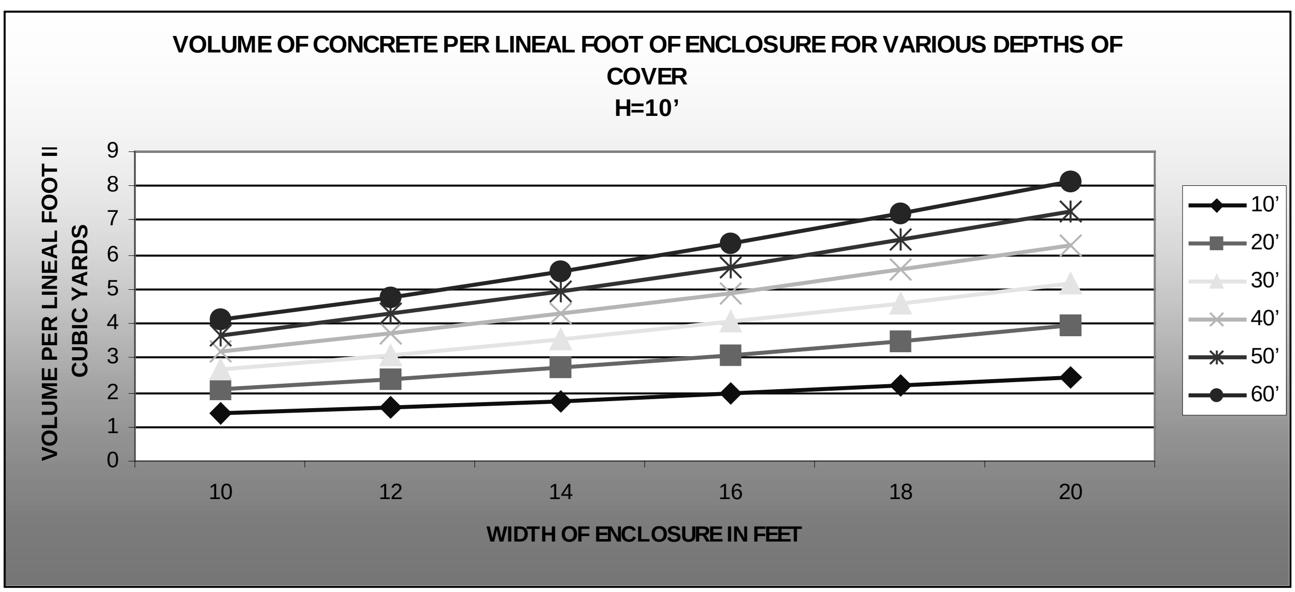


Figure 2.5 Volume of concrete of 10 feet high below grade enclosure.

Costs of cast-in-place concrete vary in northern Illinois from $200 to $500 per cubic yard, depending on whether it is a base slab, wall or roof. Base slab concrete is the most inexpensive, because little forming is required, along with little finishing labor. Wall and roof concrete is more expensive due to the forming, shoring and rebar tying required. We have found that using precast concrete does not significantly reduce the cost of a particular enclosure project. However, precast concrete enclosure sections can speed installation and reduce project costs by shortening the overall project schedule.

Deep Tunnel Construction

Many scientists and engineers believe that the next large high-energy physics facility will require a deep tunnel, for reasons ranging from radiation shielding to ground motion stability to the search for uniform geology. Fermilab has extensively studied the ongoing Tunnels and Reservoirs Project (TARP) in Chicago, Illinois. We have retained consultants and contractors to help us understand the means, methods and costs of deep tunnel construction. Fermilab is also constructing the Neutrinos at Main Injector Project (NuMI), which includes the construction of vertical shafts, a few thousand feet of TBM tunnel, and two drill-and-blast, below-grade experimental areas. The work primarily takes place in the Silurian Dolomite and Maquoketa shales approximately 90 to 350 feet below the site surface. This project will develop the lab's expertise in building and managing any large, future high-energy physics project sited in the bedrock of Northern Illinois.

The NuMI shafts range from 24 to 32 feet in diameter. They use braced excavations for the upper 90 feet in glacial materials. The lower areas are lined with concrete to redirect the inflow of water to sumps, and maintain the integrity of any loose material on the vertical surfaces. We estimate the costs of shaft construction in these diameters range from $4000 to $8000 per vertical lineal foot, depending on conditions and on the depth of glacial materials.

TBM construction can be unpredictable. Advance rates for TBM equipment are generally between 50 and 150 feet per day for diameters between 14 and 21 feet. Advance rates for a TBM depend highly on the type of rock (hardness), and on the muck removal systems required for the specific project. TBM contractors may form different strategies based on their own experiences. Thus, it is difficult to get a firm grasp on costs for a particular TBM project. However, based on our research and discussions with contractors and consultants, TBM construction in the range of 14- to 21-foot diameter can cost between $150 and $300 per cubic yard of excavated material. This is highly dependent on labor costs associated with advance rates of the machine, and on the power requirements of the equipment itself. The chart below shows the excavated volume of various TBM diameters.

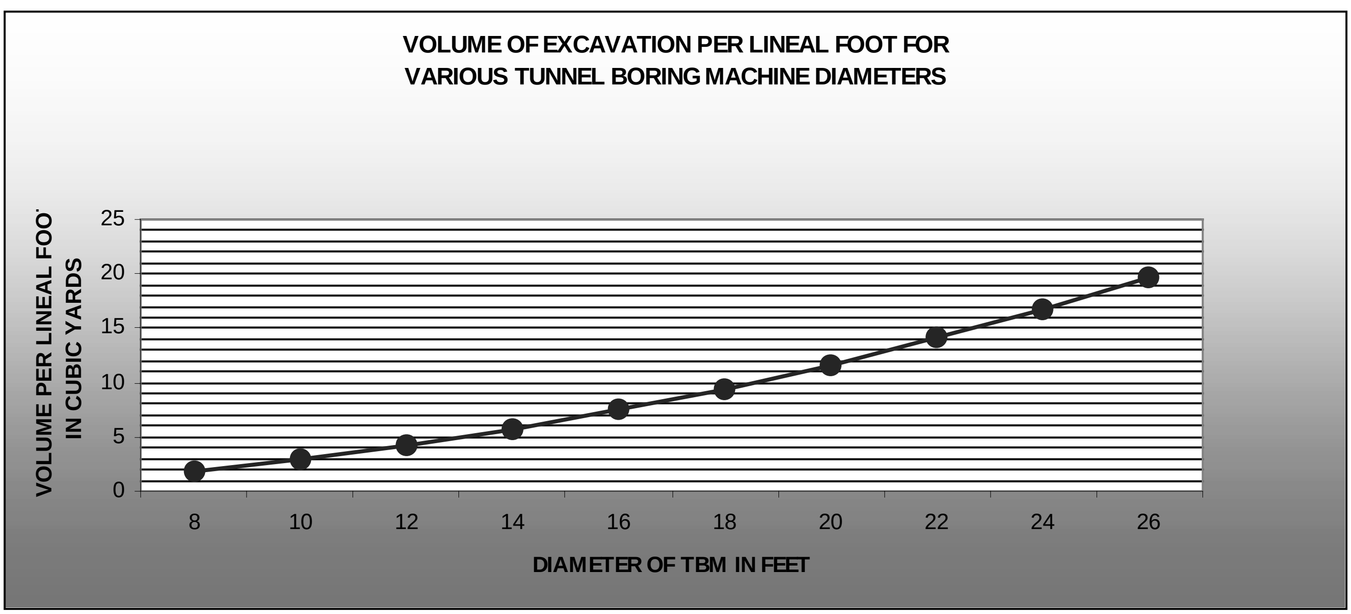


Figure 2.6 TBM Excavation Volumes

Some below-grade areas, such as interaction halls and service areas, require volumes that cannot be created by TBM methods. These areas would be constructed by a more labor-intensive, and consequently more costly, method of rock mining called drill-and-blast. This method involves literally drilling into a face of rock and setting explosives to loosen the material, so it can be removed by means of heavy equipment and conveyors. We estimate costs for drill-and-blast excavation to range from $200 to $500 per cubic yard, depending on the size of the space and on rock bolting requirements.

We recommend reading the reference materials specified in this chapter, to establish a broader context for our data and findings.

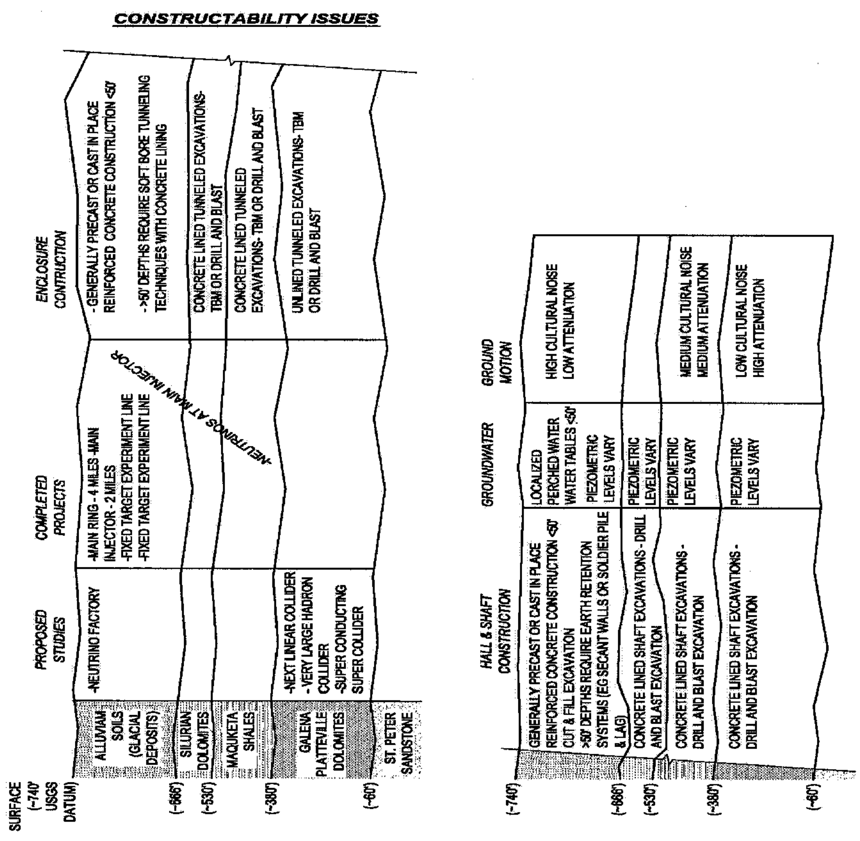


Figure 2.7 Constructability Chart

CHAPTER 3: INFRASTRUCTURE AND UTILITIES SUPPORT

3.1 Existing Utility Infrastructure Systems

Electrical

Description

Commonwealth Edison Company Electric provides power for the Fermilab Main Site from their 345 kV transmission lines, as part of over 26000 MW of electrical generation and supply contracts for northern Illinois. Transmission line 11120 is the preferred line between the Electric Junction and Lombard Substations, with Line 11119 between the Electric Junction and Wayne Substations serving as the emergency line. At Fermilab's on-site owned-and-operated high voltage substations, Kautz Road and the Master Substation, the 345 KV bus is transformed through seven (7) 40 MVA and one (1) 60 MVA transformers to 13.8 KV for underground distribution through 22 feeder breakers. Fermilab's secondary distribution consists of approximately 280 substations with 15 miles of overhead conductors and 100 miles of underground cable. In addition, 34.5 KV lines from Electric Junction serve the Village 12.4 KV overhead distribution system and provide emergency 13.8 KV from the Village and Giese Road. A Supervisory Control and Data Acquisition system (SCADA) was installed to monitor the power to the main feeder distribution systems and conduct load management opportunities.

Current Condition (reliability)

Fermilab's electrical power system is marginally adequate for current operations. The new components installed under the Main Injector Project, and selected feeders upgraded within the last few years, are rated as "good." Other secondary systems, including transformers and conductors, as well as some primary 13.8kv feeders, have elements rated as "poor," based on their current condition. When critical systems have been identified as vulnerable to failure, or when failures have occurred, those sections have been replaced.

Available Capacity

The current available capacity of the Fermilab electrical system is limited by the available high voltage substation capacity of 340 MVA (approx. 320MW). This total capacity offers considerable excess capacity for load growth. Fermilab's peak electric demand has reached an historic high of 80MW with normal operating base loads of between 35MW and 55MW offering substantial increased capacity. This available capacity is only limited geographically by the location, size and condition of feeders. Additional capacity to the Fermilab site beyond the available capacity is as close as the utility-owned 345kv transmission lines that cross the Fermilab site. These lines could easily supply any increased electrical capacity that may be required for future facilities. With existing generation capacity in the region interconnected through the Mid-America Network (MAIN), generation capacity is not expected to be a concern during summer periods of peak energy demand. Transmission of this peak energy during summer has not been a problem for Fermilab. Commonwealth Edison's regional improvement program for improving transmission and distribution will mitigate any possible concerns in this area. Further, the peaking plants being constructed near Fermilab borders would also help to mitigate any regional transmission limitations.

Planned Upgrades (capacity impact)

Consistent with the ongoing infrastructure improvement program at Fermilab, multiple feeder and equipment replacements are underway, with funding sources from General Plant Property (GPP) and the Utility Incentive Program. These projects will improve the electric feeder capacity to specific geographic locations on the Fermilab site for current requirements, and could help satisfy new requirements in a specific geographic location.

Natural Gas

Description

From two separate metered source points, gas is delivered to Fermilab by NICOR and purchased under a supply contract with the Defense Energy Supply Center. The primary gas supply is an 8-inch line metered at the Wilson Road boundary. Two branch lines extend south. One serves the Village, while the other terminates at the Central Utility Building. A second 4-inch back-up supply line has been recently completed, supplying gas through a meter station at the west boundary of the site, adjacent to Giese Road. This line is connected to the Central Utility Building gas supply. Through a system of sectioning valves, limited gas supply can be maintained to the site in the event of an interruption of the 8-inch primary supply. The pressure site-wide is regulated to maintain 100 psi. The Village and Site 38 are regulated to maintain 60 psi. Natural gas is primarily used for heating; however, it is also used to drive turbine engines for generating emergency electricity at Casey's Pond, Well #3, the Master Substation, and Wilson Hall. The site has approximately 65,000 lineal feet of underground natural gas piping, owned by the federal government and maintained by Fermilab. Fermilab currently consumes around 100,000 Deka-therms (MMBTU) per year, equivalent to one hundred million cubic feet of gas supply.

Current Condition (reliability)
The current condition of the Fermilab gas system is good as recently validated by a gas system condition survey and pressure modeling analysis.

Available Capacity
Fermilab's natural gas use is modest, by area gas industry standards of consumption per facility. It will remain so, even with the switch from electricity to natural gas as fuel for equipment, and with the addition of a filling station for alternatively-fueled vehicles. The Fermilab natural gas system could supply four to five times the current consumption, and would be restricted at that point only by limitations of pressure drops in the distribution system. Large high-pressure pipelines cross the Fermilab site, and could easily supply increased capacity for any future requirements. With the interstate high-pressure pipelines in the Chicago area, natural gas supply and distribution is expected to be adequate, even during winter's peak heating periods.

Planned Upgrades (capacity impact)
There are no planned upgrades to the Fermilab natural gas system. None is needed, as this report is written.

Pond Water Systems

Description
The Industrial Cooling Water system at Fermilab has a dual purpose. It is used to supply water to the various fire hydrants and fire protection sprinkler systems in buildings across the site. In addition, ICW is utilized in many of the experimental areas as a source for conventional magnet cooling. The distribution system for ICW extends from the main pumping station at Casey's Pond to the Support Area, Wilson Hall and Footprint Area, and most of the Experimental Areas located on the Fermilab site. The main storage reservoir for the ICW system is Casey's Pond, in the northern portion of the Fermilab site. The reservoir has two water sources. A site-wide network of lakes and ditches is used to collect runoff water, as well as water from heat exchange and sump discharge, and return it to the main reservoir at Casey's Pond. Water is also collected in the Main Ring Lake, located within the main accelerator ring, and Lake Law, located in the southeast portion of the site. The water from these lakes is then transferred to the main reservoir by means of a pumping station located at the Main Ring Lake. It is important to note that Fermilab's entire 6,800-acre site provides runoff to this network of ditches and lakes. Thus, even open areas of the site contribute to the experimental effort of the Laboratory. The second reservoir source is the Fox River. The State of Illinois allows Fermilab on an indefinite basis, when water levels are sufficient, to pump water from the nearby Fox River to supplement and maintain capacity at the main reservoir. A current Fox River dam removal project will lower the water levels at the current intake point of Fermilab's transfer pipeline. However, the project will extend the pipeline to a point where there will be no adverse impact on the lab.

Current Condition (reliability)
The current condition of the Fermilab Industrial Cooling Water (pond water) system is adequate. The main reservoir has been expanded in the last few years for increased capacity, and gas-fired turbines provide a dual fuel source for a well-maintained pumping system rated as "good." The site has about 105,000 linear feet of piping for this non-potable water distribution system, some of which is nearing the end of its useful life. The most critical sections with the highest vulnerability to failure have been identified. They have either been replaced, or are planned for replacement. The ditch

return systems and pond water control systems are in need of repair from a water conservation standpoint, but they are satisfying the current capacity needs.

Available Capacity

The present total capacity of the on-site ICW supply system is limited by the distribution system piping to 12,000 gpm. A maximum cooling demand of near 70 MW is accommodated through the surface pond group of Casey's Pond (main reservoir), Tevatron, Main Injector and CUB ponds with their associated pumping facilities. Building No. 855, the pumping station at the main reservoir, contains three 5,000 gpm primary pumps with variable-speed capacity, and four 1,000 gpm single-speed secondary pumps, which supply water to the site-wide ICW distribution system. The average pumping output of the Casey's Pond Pumping Station is primarily driven by the water temperature of the reservoir supply. This temperature varies with the time of year and the amount of experimental equipment requiring cooling. In the winter months, with minimum cooling demand from equipment, the output may be below 4,000 gpm. In the summer months, with a maximum cooling demand, the output could exceed 11,000 gpm, approaching the upper limit of the distribution system. Additional pond water systems on the Fermilab site (not connected to existing 70MW pond system) could accommodate another 150MW of cooling, for a total site capacity 220 MW of cooling.

Planned Upgrades (capacity impact)

The Fermilab infrastructure improvement program as well as the ongoing maintenance and repair program will improve piping distribution systems to enhance reliability of the current available capacity.

Potable Water

Description

Three domestic water supplies provide domestic water to the various areas of the Fermilab site. The Main Site system supplies domestic water through a piping network to the majority of the facilities on site. The primary water source for this system is Well No. 1, located near the Central Utility Building. Water is pumped from the well into a 50,000-gallon reservoir adjacent to the plant. There it is chlorinated and pumped through the site-wide distribution system. The secondary source for this system is Well No. 3, located north of Road B and east of Receiving Road. When Well No. 1 is not in use, water is pumped from Well No. 3 into a 50,000-gallon reservoir at the well site. The main site water system is owned and operated by Fermilab.

A direct-metered connection to the community water supply of the neighboring Village of Warrenville supplies domestic water to the Village Residential Area and the Village Technical Area. This Fermilab-owned and -operated system is a separate distribution system independent of the main site distribution. Besides potable water, this system provides the source of water for the fire protection systems located in the Village Areas.

Fermilab's third public water supply, located at D0, supplies water to the Colliding Beams Experimental Facility at D0. The water is pumped from nearby Well W-5 and chlorinated at D0 before distribution.

Seven additional shallow water wells, associated with pre-existing farms, serve individual buildings at outlying sites. They are kept in service to supply water to former farm residences and storage buildings still in use for laboratory requirements.

Current Condition (reliability)

The current condition of the Fermilab potable water system is adequate. The water wells are well maintained and in good condition. The distribution systems are in need of repair.

Available Capacity

The aquifer from which Fermilab wells draw water is in good condition and recharges at a rate sufficient to supply ongoing water requirements to Fermilab and neighboring communities. Wells used to draw domestic water at Fermilab have a combined capacity of 1100 gpm. The site has 32,000 linear feet of piping for potable water distribution. Total capacity of pumping stations for potable water is about 2000gpm. Current consumption averages 50,000 gallons per day, well below the site well capacity and treatment capability. Increased consumption could easily be doubled for any future increased requirement. Increased capacity would be limited only by the size of the distribution piping to a specific area.

Planned Upgrades (capacity impact)
The Fermilab infrastructure improvement program, as well as the ongoing maintenance and repair program, will improve piping distribution systems to enhance reliability at the current available capacity.

Sanitary Sewer

Description
Fermilab has two underground sewage collection systems. One serves the main site; the other serves the Village area. The main site collection system has six lift stations; the Village system has one. No sewage is treated on site. Sewage from the main site is delivered and treated on a fee basis by the City of Batavia. Sewage from the Village is handled by the Village of Warrenville under a similar arrangement. Fermilab owns and operates the sanitary collection system. The sewage system at the site contains 37,000 linear feet of gravity-feed sewage line, 12,000 feet of pressure-fed sewage line and septic tanks with a capacity of 14,000 gal.

Current Condition (reliability)
The collection system serving the main site facilities is in good working condition. A recent inflow and infiltration study identified necessary repairs and improvements to this system to increase operating efficiencies and improve the capacity of the collection system.

Recent repairs have substantially decreased infiltration in the Village system. This system is also rated in good condition.

Available Capacity
The current collection capacity of the Fermilab sanitary sewer is well above the current monthly average discharge of 3,500,000 gallons. Capacity of both the Batavia and Warrenville wastewater treatment plants is adequate for current and future requirements based on projected growth of their municipalities and can accommodate future increases from Fermilab. A limitation, if any, for future Fermilab sanitary requirements would be in the collection systems of Batavia and Warrenville, as sanitary effluent is transferred from the Fermilab collection system to the neighboring municipalities. Fermilab has a good working relationship with both City Engineers and Public Works Departments and continues to share information on many infrastructure-related issues. Although not anticipated, other possible options for increased sanitary capacity include Land Application treatment for collection of increased sanitary effluent, as adopted by some municipalities in Illinois.

Planned Upgrades (capacity impact)
Because Fermilab does not require increased capacity, there are no planned upgrades for the Fermilab sanitary system. The laboratory improves local collection systems as necessary to satisfy new requirements and eliminate existing septic fields that feed the Fermilab main collection system. Ongoing maintenance and repair improve overall capacity by decreasing the amount of storm-water and ground-water inflow and infiltration.

3.2 Requirements for Future Machines

Utility requirements for the three machines considered for purposes of this study include power (electricity) and heat load rejection (cooling). This study assumes that per capita worker consumption will generate increased requirements for natural gas, domestic water and sanitary systems. They are easily accommodated through existing and available capacity as described in paragraph I in this Section of the report.

1. Linear Collider (LC)

The study estimates that the LC would require between 200 and 250 MW of electricity, yielding the same range (200-250 MW) of cooling requirement to reject the heat load to cooling ponds located at the FNAL site. The LC may locate some of the facility off site but the surface Central Cooling Plant facilities would be housed on site.

2. Neutrino Factory (Muon Collider)

The study estimates that the Neutrino Factory proposed to be located in the Main Ring area would require 150 MW of electricity and associated 150 MW of heat load to be rejected to cooling ponds located at the FNAL site. The pond water circuit of approximately 150 acres would not interfere with current FNAL operations.

3. VLHC

The study estimates that the VLHC Stage 1 (20 TeV per beam) would require up to 40 MW of electrical power, 20 MW (30 MW installed) for cryogenic plants at two locations on the Fermilab site and five locations off-site, plus another 20 MW of power for ancillary activities such as additional component production and detector power. The VLHC Stage 2 (100 TeV per beam) would require up to an additional 150 MW (250 MW installed) of electrical power, dominated by cryogenic compressor needs to reject heating due to synchrotron radiation. The large Stage 2 installed power is for ramping the magnet power supplies, and is returned to the power grid when the magnets are de-excited at the end of a store, about twice per day. Stage 2 VLHC is essentially a large magnetic energy storage device. In Stage 1 (Stage 2) 13 MW (50 MW) of these loads would be located at Fermilab, with the remainder distributed off-site around the 233 km circumference VLHC ring. Cooling systems would be required, to reject most of these 40 MW and 150 MW heat loads. A concept to intercept the synchrotron radiation near room temperature between Stage 2 magnets looks promising; and if the development were successful, it would lower the Stage 2 power requirements by about 25 percent.

3.3 Options for Increased Utility Capacity

1. Summary Comparison of Current Capacity vs. Future Requirements

The estimates for additional utility requirements assume that current Fermilab operations would continue at up to 80 MW of power and 70 MW of cooling and that only one of the three possible future machines would be constructed.

Power	Site Utility Requirements	Site Capacity	Available Capacity	Additional Capacity
LC	200 – 250 MW	320 MW	240MW	10MW
Neutrino Factory	150MW	320 MW	240MW	0
VLHC	13 – 50 MW	320 MW	240MW	0

Cooling	Site Utility Requirements	Site Capacity	Available Capacity	Additional Capacity
LC	200 – 250 MW	220 MW	150MW	50 - 100MW
Neutrino Factory	150 MW	220 MW	150MW	0
VLHC	13 – 50 MW	220MW	150MW	0

2. Additional Utility Requirements

A. Power

Electrical power expansion capability of between 20 MW and 110 MW is available from existing Commonwealth Edison 345 KV transmission lines that currently serve the laboratory, or through some form of onsite electrical generation. The off-site power requirements for the VLHC are available from the existing electric utility power distribution grid.

B. Cooling

An expansion of the pond water system cooling capability of between 18 MW and 200 MW could come through interconnections of existing Fermilab pond capacity and construction of new ponds as needed.

Conclusions. Infrastructure and utility capacity currently exist at Fermilab or within the immediate Northern Illinois region to accommodate future experiments located either onsite or offsite. Ongoing initiatives both within and beyond Fermilab further enhance the ability to provide increased utility capacity. From an infrastructure perspective, an onsite location is the preferred approach, in order to take advantage of existing utility distribution systems and associated cost savings.

CHAPTER 4. POTENTIAL ENVIRONMENT, SAFETY, AND HEALTH ISSUES

Environment, Safety, and Health Considerations for a New Accelerator Facility

4.1 Introduction

Each of the possible future accelerators under study presents considerations in the general area of environment, safety and health. This chapter identifies the character of these challenges in a general way. The chapters related to a specific technology discuss environment, safety and health issues peculiar to a particular possible accelerator. Some of the relevant considerations are very similar to those encountered and solved during the construction and operation of other facilities at Fermilab and at other laboratories in the United States and worldwide. Others have not previously been encountered on the same scale in connection with the construction and operation of accelerators. Such novel issues will require particular attention as a project proceeds, to assure their timely resolution in a cost-effective and publicly acceptable manner. This chapter discusses both the conventional and the novel issues, with perhaps more emphasis on the latter. We conclude that with adequate planning in the conceptual design stages, these problems can be adequately addressed so as to merit the support of Fermilab, the Department of Energy and the public.

4.2 Procedural and Regulatory Matters

The design, construction and operation of any future accelerator will have to meet procedural and regulatory milestones in the area of environment, safety and health to assure timely and sustained support of the project by the public and by the Department of Energy. Devoting early attention to these issues is likely the best way to enlist public support of any chosen accelerator technology. Requirements in environment, safety and health are currently set forth as a part of Fermilab's "Work Smart Standards in Environment, Safety and Health", incorporated in the current version of the contract between Universities Research Association and DOE. Currently, Fermilab reviews the Work Smart Standards annually to assure that they adequately address the hazards of the laboratory, including those of any new facility. If changes are necessary, the laboratory negotiates them with the DOE-FRMI Group; and the URA-DOE contract is revised accordingly. The standards include listings of applicable federal and state regulations as well as internal policies and national standards (WSS 99). Of course, the contract under which a future accelerator might operate in the future is likely to change in ways that could modify the applicable requirements.

A. Environmental Protection Procedural and Regulatory Matters

All DOE activities are subject to the requirements of DOE's regulations for implementing the National Environmental Policy Act (NEPA) (CFR 97). First, any new project of the magnitude of those under consideration in this report will require an Environmental Assessment (EA). A review will study all possible impacts of the project on the environment and the public. The required analysis is broad in scope and includes societal impacts along with topics that are more generally associated with environmental protection, such as the discharge of pollutants, effects on wetlands and floodplains, and exposures of people to chemicals and radioactive materials. The EA will include a review of the alternatives of carrying out the project elsewhere or not at all. This process focuses on the production of a comprehensive document but also includes the participation of the public by methods chosen by DOE. As a result of the environmental assessment process, DOE will either issue a Finding of No Significant Impact (FONSI) or conclude that that the preparation of an Environmental Impact Statement (EIS) is necessary. The Department is likely to require an EIS due to the size, scope, cost and impact on the human environment of the project. In particular, DOE will almost surely require an EIS for any new facility that extends beyond the present boundary of the Fermilab site. The completion of the EIS results in the issue of a formal public notice called a Record of Decision (ROD). The EIS process is generally considered to be an arduous one, but one that can be followed to a successful conclusion in the ROD. The preparation of an EIS is certain to be a large and costly task; it is customarily accomplished using external resources. Regardless of the eventual path of the NEPA process, project funds cannot be issued to support such a project beyond the early conceptual stage before successful completion of the NEPA process. It is thus crucial to conduct this process honestly and in a way that substantively and straightforwardly addresses the concerns of members of the public. A good working relationship with DOE is also a prerequisite to a successful result.

Other procedural requirements apply in the area of environmental protection. The NEPA process will identify them more certainly, but early planning may avert problems later. DOE facilities are generally subject to federal and state environmental protection regulations promulgated chiefly by the U. S. Environmental Protection Agency (USEPA), the Illinois Environmental Protection Agency (IEPA), and the U. S. Army Corps of Engineers (COE). Any of the possible accelerators will require environmental permits from both state and federal authorities. Some apply during the construction stages, others apply during operations, and some apply during both stages. Required permits cover such topics as storm water discharges, discharges of cooling water, wetlands impacts, releases of air pollutants for both non-radioactive pollutants and for radionuclides, and construction in any floodplains. Archaeological sites that may exist in the region need further investigation and study prior to the commencement of construction. The preparation of the applications for these permits and approvals is generally straightforward, but must be accomplished with the long lead times, from 180 days to a year or more, required by the issuing agencies. Early coordination with the project design team should greatly facilitate completion of the associated milestones.

The public and federal and state regulators are likely to have an initial view of any chosen accelerator as a poorly understood, esoteric technology. For this reason, and because any of the chosen accelerators will involve some sort of impact beyond the geographical boundaries of the present Fermilab site, early coordination with the federal and state regulatory agencies will promote better understanding of the nature and impact of the chosen facility. It is most important to submit required applications early.

B. Safety and Health Procedures and Regulatory Matters

In accordance with the Fermilab's Work Smart Standards, the laboratory will be required to prepare an assessment of the environment, safety and health issues associated with this project in the form of a Safety Assessment Document (SAD). Given the size, scope, cost, and novelty of any of the candidate facilities, the laboratory will need to prepare a first stage document called a Preliminary Safety Assessment Document (PSAD). The purpose of the PSAD is to identify the relevant environmental, safety and health issues at an early stage and propose how to mitigate them. A final Safety Assessment Document then documents the resolution of the pertinent issues raised by the PSAD. Environmental issues are customarily integrated into the PSAD/SAD process to promote program cohesiveness. Given the scope of any of the candidate projects in this report, it is nearly certain that DOE will choose to review these safety documents with an external review team composed of both DOE staff and representatives from other DOE laboratories. Just prior to facility operation, an external review team will conduct a readiness review. DOE has specified a somewhat more rigorous procedure for the conduct of this safety review process in its Orders. The details of the procedures for the safety review process will be determined by the terms of the contract under which the laboratory is operated at the time the project proceeds. Unlike NEPA assessment activities, PSAD/SAD activities generally begin after funds are issued. Nevertheless, careful consideration of PSAD/SAD in the design can only have beneficial results. Efforts should begin at early stages to promote consistency between the conclusions of the NEPA assessment and the safety and health documentation.

DOE is presently "self-regulating" in the areas of industrial safety and occupational radiation protection. It is possible that during the development of the next accelerator facility, DOE activities might become subject to "external" regulation in these areas, as well as in occupational radiation protection. We cannot now anticipate the form such external regulation might take or which agencies might be involved. Fermilab staff and DOE continue to monitor the status of DOE self-regulation in order to identify new requirements or procedures that might apply to laboratory activities.

4.3 Fire Protection and Life Safety Considerations in Design Phase

Based on the assumption that the next generation of accelerators at Fermilab will be located at some depth underground (30-800 feet), the design phase must consider certain life safety and fire protection issues. These issues include means of egress, which will have a large impact on the design and thus the cost of the accelerator; the use of refuge areas; smoke control; fire protection; fire suppression; emergency power needs; and emergency preparedness.

Currently there are no standards that cover an underground accelerator. Fermilab contracted with the firm of Gage-Babcock to research these life safety and fire protection issues both for the design of NuMI and the Next Linear Collider and to identify applicable design standards and preliminary recommendations. The recommendations that arose from that study included establishing fire resistive separations for the tunnels, cross connections and openings, at least two elevators in every shaft to the surface, separation distances for cross connections based upon the use of “refuge areas,” independent ventilation systems for the Service Tunnel and Beam Tunnel and automatic sprinkler protection throughout the facility, etc (GBA 00). The recommendations for the NLC tunnel may, or may not, apply to other underground accelerators, depending on the complexity of the tunnels, the amount of flammable material, and the types of hazards that exist. Each tunnel must be evaluated as part of its specific design.

4.4 Occupational Safety During Construction

Any of the accelerators under consideration will involve a large-scale construction. In regions where the familiar "cut and fill" method applies, the laboratory would follow the standard practices embodied in the Occupational Safety and Health Administration's (OSHA's) regulations on the safety of construction activities (see WSS 99). Particular requirements that address excavations, the provision of applicable personnel protective equipment, coordination of emergency response measures, fire safety, chemical safety, and electrical safety would apply as they have for many years to other civil construction projects on the Fermilab site. The project would need to provide adequate means of egress for construction workers. Given the nature of the candidate facilities, which are somewhat unlike present facilities, some locations may call for significant slopes. The design should include well-thought-out means of preventing accidents due to heavy objects moving.

The candidate facilities all involve extensive tunneling in bedrock units, some horizontal and some with slopes. Besides the safety requirements pertaining to construction activities, federal regulations pertaining to underground operations (e.g., "mining" activities) come into play. Fermilab is developing solutions to these issues to address challenges of this type encountered in the excavation for the NuMI project. The challenges include the standard concerns about tunneling safety and material movement as the tunneling proceeds. The choice of construction methods between the use of Tunnel Boring Machines (TBMs) and the employment of drilling and blasting methods will most likely be one of economics or availability. Either alternative has associated occupational safety considerations and will require provision for emergency response including underground rescues. Again, egress issues relevant to protection of the construction workers will have paramount importance.

Given the location within several major aquifers, and the existence for some facilities of downward slopes at certain locations, it is clear that the design must include stringent measures to prevent flooding during construction and operation. The design must address this problem in harmony with the related environmental protection concerns (see Section IV). Likewise, any downward slopes in the bedrock units will require the same attention to the prevention of uncontrolled movements of heavy objects downhill as in the "cut and fill" zone. While such control measures are familiar in mining operations elsewhere, they are novel for accelerator laboratories. The existence of steep slopes also needs to be carefully considered in planning for emergency rescue operations that might be needed during construction.

Project construction is likely to employ industrial radiography, a tool commonly used in general industry, to assure the quality of7 pipe welds, etc. Such radiographic operations, which typically use radioactive sources of high activity, relatively hazardous compared with the sources commonly used in particle physics experiments, would need to be conducted in compliance with the pertinent requirements of the State of Illinois. In the course of construction, other radiation-generating devices such as soil density gauges and media water-content probes might also be used, requiring the application of standard procedures pertaining to such activities.

4.5 Environmental Protection During Construction

All of the candidate facilities will be completely or partly underground. Some pieces will be located near the surface, in the glacial till, while others will be located deeper underground in the various rock strata. For the pieces near the surface, construction may proceed by cut and fill techniques like those used to build most of the present facilities at Fermilab. The laboratory will employ erosion control measures like those in practice for a number of years in accordance with good engineering practice and federal and state regulations, and with relevant regulatory agency guidance (IE 99). The project must control dust and runoff from spoil piles. Likewise, the project will need to develop a storm water management plan. At present, if the construction affects five acres (2.0 hectares) or more of land surface, the project requires a National Pollutant Discharge Elimination System (NPDES) Stormwater Permit for construction. It will dictate specific actions during the construction period. It is possible that the regulatory threshold in the near term future may decrease from five acres to one acre. The project will need to take the usual precautions to prevent pollution from spills of regulated chemicals from the construction equipment. Noise from construction activities is unlikely to be significantly larger than that associated with normal civil construction activities in the vicinity of Fermilab. Note, however, that noise from such activities has already proved to be a significant community relations issue.

The NEPA process described in Section 2A should result in a determination of the impact of the project on wetlands and floodplains. The process will include a general description of how any identified effects will be mitigated. For example, if the process identifies more than three acres of wetlands, it may be necessary to create compensatory man-made wetlands. Rearrangement or enlargement of the Fermilab pond system might prove necessary to compensate for possible interference with floodplains. It may be especially important to demonstrate adequate care for floodplains due to significant local public concerns about flood prevention.

Tunneling in the bedrock units will result in the removal of a large volume of rock. The management of the spoil is a major issue, and the project must make provisions for its proper stockpiling. In particular, concerns about dust and runoff may be especially severe for pulverized rock. The length of storage may be temporary for spoil that is of marketable quality, longer for spoil requiring reuse at Fermilab or disposal. Stockpiling should take into account Fermilab's longstanding tradition of placing high importance on aesthetic issues. The management of spoil materials will need especially vigorous attention if the project requires its removal at offsite locations. The placement of such a project in any aquifers requires the protection of drinking water resources from contamination during construction. The "dewatering" of tunnels as the construction proceeds will require the development of measures to prevent the depletion of wells and to manage any additional water discharges from this source.

The storm water management plan will need to take into account any releases of groundwater generated in the course of "dewatering" the tunnel. Understanding the interplay of the construction of the project with the various aquifers will require careful hydrogeologic studies to establish with certainty that construction will not cause significant perturbations of the local individual and municipal water supplies, either in quality or in quantity. It should be mentioned that the exact depth of the various aquifers is not known in detail at all locations involved in the facilities discussed in this report. Accurate measurements will be needed, through geological investigations over the entire affected region. The results can be used to plan a strategy for preventing the tunnel from serving as a possible path of cross-contamination from one aquifer to another. During construction activities, the project will require precautions to guarantee that spills of chemicals, including lubricants and fuels from the construction equipment, are captured before they enter surface water or groundwater. The presence of any downward slopes presents special considerations in this regard. The project may also require non-coal-mining NPDES permits issued by the Illinois Environmental Protection.

Tunneling activities can generate noise and vibration. Should the construction require blasting, quantitative standards apply to the amplitude of the vibrations allowable at the surface. The project will need to address noise exposure, both occupational and to the public at the site boundary and at offsite locations. Fermilab's recent NuMI experience has shown that these are not trivial considerations.

4.6 Occupational Safety During Operations

A. "Ordinary" Occupational Safety Hazards

All of the candidate facilities will present the occupational safety hazards encountered at all other large particle accelerator facilities. In this section, we focus on the issues successfully addressed before, at Fermilab and elsewhere, by well-known techniques. They are listed here, along with the corresponding safety and health needs, simply for completeness:

- The facility will use high current electrical circuits on a large scale. Present techniques in managing power distribution and providing means to effectively lock out supplies should be adequate to address the electrical hazard.
- The accelerator will use radiofrequency (RF) generation and distribution equipment. Present techniques for controlling possible exposures to non-ionizing radiation should be sufficient.
- All of the accelerators will have some tunnel sections with large numbers of cables in cable trays. Current methods for addressing fire protection concerns should be adequate. The arcs of the VLHC tunnel have few cables and a much lower fire hazard.
- The accelerator will have long tunnels. They will require addressing Life Safety Code and fire protection issues to assure adequate provisions for egress and adequate means of prevention of and response to fires.
- There will be movements and alignment of large, heavy components. The design must include considerations related to ease of movement of equipment to prevent injuries.

Applying the present collective experience to the design at an early stage can address all of these issues.

B. Novel Occupational Safety Hazards

This section focuses on occupational safety hazards not generally encountered at accelerator facilities. These will all require consideration in the early planning stages.

i. Large-Scale Use of Cryogens

Some of the facilities require the extensive use of superconducting materials and related cryogenics in both magnets and RF structures. While these technologies are relatively new, several accelerators worldwide, including the Tevatron at Fermilab, have developed techniques for addressing them. Designs will need to provide for the safe release of cryogens to the surface during normal operations and in the event of emergency cryogen relief. Current accelerator facilities have employed skilled engineers to independently review such systems for safety during the design and commissioning stages, with the resulting development of a number of standard engineering practices to mitigate both direct cryogenic hazards and the accompanying oxygen deficiency hazards (ODH). This general approach should adequately address such concerns.

ii. Ionization Cooling Technology

Some concepts involve the use ionization cooling, a technology that presents novel hazards. The use of liquid hydrogen (LH_2) is being considered as a possibility preferable to using hazardous or toxic materials. While this choice may be preferable from environmental protection and industrial hygiene standpoints, due to the lack of the potential for spills or exposures to hazardous or toxic materials, the fire and explosion hazard represents an important consideration. In an ionization cooling system, the LH_2 cells would be interleaved with RF structures and magnets that apply a high electrical energy. The impact of the absorption of energy from the particle beams gives pause. In view of these considerations, a review committee of qualified specialists should convene at the earliest reasonable state in the design of any facility that incorporates this technology, to assure safe and cost-effective solutions.

iii. Use of Plastics

The types of materials allowed into tunnels and enclosures will have great significance. In a deep underground enclosure, the design must give great importance to the hazards associated with density, toxicity, and corrosiveness of smoke from burning plastics. This is an issue of great concern at CERN. Halogenated materials such as PVC, neoprene or Teflon give off irritating, thick, acidic and often highly narcotic smoke. Other halogen-free plastics that have been shown to produce thick, toxic and corrosive smoke include ABS and polyurethane.

The next generation of accelerators must be designed free of undesirable plastics, scintillator materials and other materials. The next generation of accelerator teams would do well to establish tight control over the materials introduced into the enclosures. Wherever possible, they should incorporate only plastics and other materials that exhibit satisfactory fire performance, are free from halogens and sulfur, and exhibit low smoke density, low toxicity and low corrosiveness of fire gases.

In cases where physics performance is affected or the cost is prohibitive, designs must mandate engineered mitigations to reduce the hazards to an acceptable level. A committee for fire protection should review the materials and mitigation methods to ensure identification of the appropriate automatic and manual fire suppression techniques.

iv. High Power Lasers
New accelerators will probably use high-powered lasers to manipulate particle beams and also perhaps as a source of photons for experiments. While the hazards involved with the use of such lasers are well known and specific standards are in place to mitigate them (WSS 99), the design should pay careful attention to the corresponding safety considerations at early stages of design.

4.7 Ionizing Radiation Safety During Operations

A. Prompt Radiation Shielding

All of the possible choices of the future accelerator will likely require significant amounts of passive shielding to attenuate prompt radiation to levels acceptable to the public. Indeed, the proposed siting of these facilities deep underground implicitly recognizes this concern. The shielding demands of proton accelerators are generally recognized to greatly exceed those of electron machines, especially with regard to attenuating the neutrons produced at large angles. At the forward angles, given the copious production of muons, and the increased importance of range-energy straggling at high energies (Va 87), the shielding requirements of any of the new machines increase rapidly with energy and must be well understood at the earliest possible stage in the design and in the NEPA process.

More detailed understanding of the pertinent requirements must precede further discussion. Current DOE requirements are not well matched to discussions of radiation fields beyond the boundaries of DOE sites. DOE has specified the annual limits on the radiation dose equivalent that can be received by occupational workers and members of the public (see Regulation 10 CFR 835 in WSS 99 and DOE 93). These limits, in all situations expressed to date, pertain to the dose equivalent delivered to people or to locations where people could reasonably be. For individual members of the public, the primary limit is 100 mrem (1 mSv) in a year, not including man-made, medical or enhanced natural radioactivity. This limit is intended to apply to all sources of radiation exposure that a person might receive, even from non-DOE manmade sources. Special reporting requirements apply when the annual dose equivalent received by an individual exceeds 10 mrem (0.1 mSv) in a year. DOE has expressed the view that non-occupational annual doses to real members of the public must not exceed a few mrem in a year.

In light of public concerns about radiation exposures, the design for any new facility should keep the dose that could be reasonably received by members of the public as low as possible. Higher annual dose equivalents at underground locations inaccessible to people but beyond the control of the host laboratory might be allowable. The project should select these criteria early in the NEPA process, with the support of DOE secured. As a convenient reference point, the average annual radiation dose equivalent received by people living in the United States is about 360 mrem (3600 microSv). Of this exposure, about 300 mrem (3000 microSv) is due to natural sources, including exposure to radon indoors (NCRP 87).

While the proper shielding against hadrons (mostly neutrons) and electrons at high- energy accelerators is quite well understood, most of the new facilities under consideration must solve several new problems. The likely large dimensions of the facility coupled with the long ionization ranges and the increased importance of the range-straggling phenomenon of muons in any new regime of higher energy will require taking into account the curvature and profile of the earth's surface to assure valid shielding calculations. Also, for some facilities prompt radiation dose due to neutrinos may arise as a significant consideration for the first time (Mo 99). Both of these problems have considerable impact on the selection of the "footprint" of controlled and uncontrolled property that is needed for or affected by the facility.

B. Residual Radioactivity of Components

Several of the accelerators under study will have portions that must handle beam powers of unprecedented magnitude. As is well known, in the high-energy region, most, but not all, of the radiation effects scale roughly with the beam power for either accelerated electrons or protons. In particular, designers should carefully take into account the effects of high residual activity at early stages of the design of collimation systems, targets, ionization cooling apparatus, and other sites of possible high beam losses. The use of materials in the target stations of high atomic number, which might not be solids at their operational temperature, merits significant, early attention as plans proceed and choices evolve. Doses that might be received by workers are important for the NEPA process. It is critical to minimize the generation of radioactive wastes and to eliminate the creation of wastes that contain materials that are toxic or hazardous and that contain radioactivity at all points during the design effort.

C. Airborne Radioactivity

The production of airborne radioactivity at a future accelerator needs careful consideration. Federal regulations promulgated by the U. S. Environmental Protection Agency (EPA) have established an annual limit on dose equivalent of 10 mrem (100 microSv) to any member of the public received due to airborne releases of radioactivity resulting from operations of DOE facilities such as accelerators (CFR 89). Further, the same regulations impose stringent continuous monitoring requirements if the annual dose equivalent to any member of the public is to exceed 0.1 mrem (1 microSv) in one year. In addition, if the level of 0.1 mrem in one year is to be exceeded, then applications for approval to construct and a notification of startup must both, in proper sequence, be submitted to the U. S. Environmental Protection Agency. Given the nature of the proposed facilities and their extent beyond the present boundaries of the Fermilab site, facility designs must pay careful attention to controlling the production and release of airborne radioactivity. The high beam power of any of the possible machines can lead to the production of airborne radionuclides that, while generally of short half-life, have the potential to deliver annual doses above allowable levels in areas accessible to the public. Care in design should be able to mitigate these releases.

D. Radioactivity in Soil and Groundwater

The placement of any of the future facilities in both the glacial till and the underlying bedrock requires that the design give careful attention to the production of radioactivity in these hydrogeologic units. Again the anticipated beam powers dictate careful consideration of such radioactivity. Detailed hydrogeologic studies to determine the relevant parameters precisely, because they are known to vary significant in the vicinity of the Fermilab site, should precede determination of the exact footprint of any chosen facility. It is clear that protection of groundwater against contamination with radioactivity merits early, detailed attention in project design to assure addressing likely public concerns. It may well be that the most prudent choice of design objectives should be far below present regulatory standards for drinking water.

4.8 Non-Radiological Environmental Protection Issues During Operations

Operations of the facility should be planned so as to control the generation of non-radioactive wastes. Further, the design must address potential spills of hazardous or toxic materials in a way that fully protects members of the public as well as environmental resources. The NEPA process will require detailed attention to these issues, and the designs should provide information needed to support all required permit applications to state and federal environmental regulatory agencies. For the operational facility, the design must prevent cross-contamination of the various aquifers in any enclosures located deep underground, and any dewatering operations must assure that local community or individual drinking water supplies are not perturbed.

4.9 Summary

All of the candidate facilities provide challenges in the area of environment, safety and health. Other accelerator facilities have already encountered and addressed many of them. Some of the problems are common to other projects at Fermilab and elsewhere that have produced in new solutions. Given the new scale of any of the candidates, and their nature, some of these issues may have a greater importance than previously encountered. This study concludes that with adequate planning in the design stages, these problems can be adequately addressed in a manner that merits the support of the laboratory, the Department of Energy and the public.

References

CFR 89 United States Code of Federal Regulations, Title 40, Part 61, Subpart H, "National Emissions Standard for Hazardous Air Pollutants (NESHAP) for the Emission of Radionuclides other than Radon from Department of Energy Facilities", 1989.

CFR 97 United States Code of Federal Regulations, Title 10, Part 1021, "{Department of Energy} National Environmental Policy Act Implementation Procedures", 1997.

DOE 93 U. S. Department of Energy, "Radiation Protection of the Public and the Environment", DOE Order 5400.5, January 7, 1993.

GBA 00 Gage-Babcock & Associates, “Next Linear Collider – NS”, July 26, 2000, 98019-14-1.

IE 99 Illinois Environmental Protection Agency, *Illinois Urban Manual; a Technical Manual Designed for Urban Ecosystem Protection and Enhancement*, prepared by the United States Department of Agriculture, Natural Resources Conservation Service, 1902 Fox Drive, Champaign, IL 61820 (1999), www.il.nrcs.usda.gov/engineer/UrbManBro.html.

Mo 99 N. V. Mokhov and A. Van Ginneken, "Neutrino Induced Radiation at Muon Colliders", presented at the 1999 Particle Accelerator Conference, New York, New York, March 19-April 2, 1999, FERMILAB-Conf-99/067.

NCRP 87 National Council on Radiation Protection and Measurements, *Ionizing Radiation Exposure of the Population of the United State and Canada from Natural Background Radiation*, NCRP Report No. 94, December 1987.

Va 87 A. Van Ginneken, P. Yurista, and C. Yamaguchi, "Shielding Calculations for Multi-TeV Hadron Colliders", Fermilab Report FN-447 (1987).

WSS 99 "Fermilab Work Smart Standards Set", Fermi National Accelerator Laboratory, http://www-lib.fnal.gov/library/protect/worksmart.html, November 15, 1999.

CHAPTER 5. PUBLIC CONCERNS AND COMMUNITY INVOLVEMENT

5.1 Introduction, Background and Scope of Our Considerations

The Fermilab accelerator complex and supporting infrastructure represent a significant public investment. As we embark toward new frontiers of energy and discovery, it will be most productive to make use of existing Fermilab infrastructure, expertise and capabilities.

A key issue in planning major expansions of Fermilab's research capabilities is gaining public support. Any future accelerator project will require support not only for the science mission of a new facility but also for its construction in the community. Many constituencies have stakes in Fermilab's future. Among the most important are our neighbors. Moreover, Fermilab's expansion may require going beyond current site boundaries. Because we have not yet defined the best path to follow for the future, we have the opportunity to begin a dialogue now with our neighbors to involve them in the process of planning, and to inform them of our current R&D efforts and future options. This chapter deals with what we know about our neighbors' attitudes, and discusses possible strategies for engaging their participation in the planning of future facilities.

Discussion of Fermilab's vision for the future has already entered the public consciousness via the media. It seems clear from the few negative comments received that any proposal for a new accelerator facility must differentiate itself from the failed "SSC in Illinois" proposal, in particular by establishing a higher degree of freedom early on in defining the footprint of any new facility. We will have to choose the site for any future facility in partnership with local organizations and people, so that they become part of the creative process.

Sections 2 and 3 identify external interests, environmental, social and economic, that will be affected by plans for future Fermilab facilities.

Many in the general public find science, and particle physics and astrophysics in particular, exciting subjects. However there are many who have little understanding of what we do at Fermilab and who harbor misconceptions about our work. Apprehension about the research performed at Fermilab is a potential byproduct of such misconceptions. A first set of focus groups and a public opinion survey have explored these issues. Section 4 discusses these results.

In Section 5 we enumerate possible strategies to enlist the participation and support of our neighbors in Fermilab's long-range future. This program of outreach will continue to develop over the years to come. Part of our job will be to learn from the experiences of other major projects and laboratories: SSC, SSC for Illinois, DESY, and CERN's LEP/LHC project. Local situations (e.g. Commonwealth Edison's placing of high voltage power line along the Illinois Prairie Path), while they are not high-energy physics projects, can nevertheless be instructive. The focus groups and opinion survey point out the need to do a better job of informing the public of our activities.

Local support will depend on the perceived benefits of our research to society: increase of knowledge, prestige, jobs and positive influence on education; as well as on perceived drawbacks and risks of our activities. Our task is to discuss these issues with our neighbors and listen to what they say. We will be asked about the "use" of an expansion of Fermilab. We must be forthright and honest in our answers.

5.2 Identification of External Interests That Will Be Affected by Plans for Future Fermilab Facilities

Fermilab's future direction as a physics laboratory will have the most direct effect on the worldwide community of scientists who use its facilities to carry out experiments at the frontiers of particle physics. However, the laboratory's future will have significant effects on other groups as well. In particular, residents of neighboring areas; state and local governments; local businesses and organizations; schools; media; ecological researchers; environmental and conservation groups; and those who use the laboratory and its campus as an educational, cultural and recreational resource all have a stake in Fermilab's future. Fermilab's neighbors comprise all of these groups.

Our neighbors will be affected no matter what future Fermilab follows: if no new accelerator is built at Fermilab; if a new accelerator is built on the existing site; or if Fermilab constructs an accelerator that extends beyond the site boundaries. Although we cannot say with certainty what Fermilab's future will be if no new accelerator is built in Illinois, a credible prediction is that the laboratory would retain a modest physics program while providing support for facilities in other countries. In such circumstances, it is likely that the laboratory would operate with scaled-back resources and a smaller staff, making a correspondingly smaller contribution to the local economy. Under those circumstances, it might become significantly more difficult for the Department of Energy to justify the use for physics research of the large Fermilab site, with its location in the developing suburbs. We could anticipate significant pressure from sectors of the local community to devote the Fermilab site to what could be viewed as more directly productive purposes. Clearly, there would in any case be significant effects on all the above groups of stakeholders.

Equally clearly, most of our neighbors would also be affected, although very differently, by the construction of an accelerator that extended beyond the Fermilab site. Identification of concerns related to expansion is one of the goals of the public opinion survey described in Section 4. Fermilab must recognize, understand and respond effectively to these concerns.

Perhaps the construction of a new facility contained within the current laboratory boundaries would have the least effect on outside stakeholders, but even such a facility would have considerable economic, social and cultural impacts on most of the groups.

5.3 Demographics of Northeastern Illinois.

Fermilab lies approximately 35 miles west of Chicago, straddling the border between DuPage and Kane Counties. The immediate area is primarily suburban and is currently experiencing rapid growth. Planning for the six-county Chicago metropolitan area is the responsibility of the Northeastern Illinois Planning Commission (http://www.nipc.cog.il.us/).

The NIPC covers the counties of Cook, DuPage, Kane, Lake, McHenry and Will. These counties occupy the northeast quadrant of the site-studies area; encompass the bulk of the population; and are the most demographically dynamic. The six counties comprise 3,749 square miles of land and water. As of the most recent survey (1990), 40 percent of this land was in agricultural production; this figure is undoubtedly lower now. The currently estimated population of the area is 7.8 million people. Estimates call for growth of over 9.0 million by 2020. Table V.1 contains projections by county. As the table shows, projections show that Kane County, home to Fermilab, will be among the more rapidly growing areas in the Chicago area over the next two decades. The overall populations and population densities of the counties to the north and east of Fermilab (Cook, DuPage, Lake) present special constraints to siting a new facility there. Counties to the west of Fermilab, starting with DeKalb remain predominantly rural. It would behoove Fermilab to establish a relationship with NIPC, as well as with the counties to the west, in discussions of the future of Fermilab.

COUNTIES	1990 Census	1999 Estimate	2020 Projection	1999-2020 Projected Increase
COOK	5,105,067	5,192,326	5,615,278	8%
DUPAGE	781,666	892,547	985,704	10%
KANE	317,471	406,622	552,034	36%
LAKE	516,418	617,975	806,779	31%
MCHENRY	183,241	246,812	347,159	41%
WILL	357,313	478,392	738,046	54%

Table V.1: Population growth projection for the six-county area between 1990 and 2020. (Source: Northeastern Illinois Planning Commission)

5.4 Summary of Community Attitudes Toward Fermilab and Its Future

As part of gathering information for this report, Fermilab asked the Northern Illinois University Public Opinion Laboratory to conduct a thousand-response public opinion telephone survey covering an area including parts of DeKalb, Kane and western DuPage counties. The survey's goal was to establish a baseline on community knowledge and attitudes towards Fermilab as it exists today and to explore issues that in the public's consciousness that may affect Fermilab's future.

To help choose and formulate the questions for the survey, NIU/POL conducted five focus groups encompassing 40 people in the fall of 2000. The statistics were limited because of the small sample, but the focus groups reflected some uncertainty about what Fermilab actually does and some modest level of concern about the hazards posed by the laboratory. Among the other trends evident in the focus group discussions.

- Most focus group participants understood that Fermilab did "something nuclear," but were uncertain of the details beyond this.
- Many focus group participants acknowledged their lack of understanding and recognized that lack of understanding could lead to fears and concerns about our activities. In general participant lack of understanding was attributed to lack of effort on the part of Fermilab.
- Many appreciated Fermilab as a cultural and recreational resource and generally viewed the lab as a good neighbor.

Following the focus groups, NIU/POL undertook the public-opinion survey in the late winter and spring of 2001. Using information from the focus groups, Fermilab and NIU/POL designed the survey to assess current attitudes toward Fermilab and to identify potential future community issues. The public opinion survey covered roughly the same geographical area as the focus groups. A preliminary analysis of the survey provides the following interpretations:

1. **The community appears supportive of science and technology**.
    - 91 percent strongly agree/agree that science and technology make life healthier, easier and more comfortable.
    - 96 percent strongly agree/agree science and technology advance human knowledge.
    - 82 percent strongly agree/agree scientific research advances knowledge and should receive government funding.
    - Over one-quarter (29 percent) are very interested in science and technology issues while 35 percent are very interested in new medical discoveries.

- 91 percent say the benefits of scientific research outweigh the drawbacks.

2. In general, the community seems favorable toward Fermilab.

- 98 percent say Fermilab should either expand operations (50 percent) or maintain operations as now (48 percent).
- Over half (54 percent) would be in favor of Fermilab expanding beyond its present boundaries.

3. **Fermilab has an opportunity to educate a community that is hungry for more information**.

- Though almost half (47 percent) are very or somewhat familiar with Fermilab, over half (53 percent) say they are not too familiar or not familiar at all.
- 36 percent say they haven't read or heard anything about Fermilab in the last 12 months.
- 82 percent haven't heard or read anything about Fermilab's outreach programs to the community.
- Of those familiar with Fermilab, 23 percent say they have visited the lab, while 86 percent of those who haven't visited say they would visit if provided an opportunity.
- There is a gap between interest levels in science and technology, new medical discoveries and environmental issues (in the 80^{th} percentiles) and actual knowledge levels about these issues (in the 70^{th} percentiles). Fermilab can help close that gap.

4. **Media appears favorable – but that can change quickly. Fermilab needs to reinforce and build relationships directly with stakeholders to maintain support in times of negative press.**

- The good news is, over half the respondents (59 percent) feel the media is not biased; one-quarter say they're biased in favor of Fermilab.
- 93 percent say the majority of media coverage of Fermilab is positive.

5. **Though it appears the community trusts Fermilab, there is some skepticism and concern regarding environmental safety – in a community where interest in environmental issues is high.**

- 90 percent say they trust management at Fermilab to do the right thing environmentally; 81 percent feel Fermilab is open to feedback from community members.
- 38 percent of respondents are very interested in environmental issues; more than science and technology or new medical discoveries.
- While 53 percent consider Fermilab very safe, 39 percent say it is somewhat safe – *verbatim responses will be key to understanding specific concerns.*
- 21 percent say they are not comfortable buying a home near Fermilab, indicating some degree of discomfort regarding environmental implications.
- 23 percent oppose Fermilab's expansion beyond its present boundaries.

6. Timely communication is an area Fermilab can improve.

- 38 percent say Fermilab does not provide timely information to the community.

5.5 Recommendations for Community Outreach and Community Involvement in Defining a Future Facility

Fermilab would of course like our neighbors to recognize and appreciate what we are and what we do, and to attach value to both our current and future presence in this area. Fermilab will also require community support if a new facility is to be built on or in the vicinity of the laboratory site. Achieving such support requires an interactive process in which the laboratory itself seeks out and accepts attitudes and views of the public while simultaneously reaching out to inform and engage our neighbors in the activities of the laboratory.

This section focuses on what Fermilab can do to enhance the knowledge of and appreciation for Fermilab's role within the surrounding communities, and to engage the public in the process of determining future directions for the laboratory. Approaches taken to influence opinion positively will differ with each constituency, their agendas and interests, and with their level of knowledge of our field. We start with the basic assumption that among the general public there is interest in science and an appreciation for the importance of education, but that the level of real knowledge of science (and its language, mathematics) is generally low. Any approach must recognize that attitudes are not shaped solely by information transmitted directly or via the media, but also by how people react to experiences on and around our site—its accessibility, and the cultural, environmental, and recreational activities they engage in.

We imagine a strategy for achieving these goals that is based on:

- Creating and sustaining institutional and personal relationships between Fermilab and members of the community
- Understanding current community opinions and attitudes towards Fermilab
- Reaching out to inform the public of what Fermilab is and what we do
- Involving the public in the process of defining Fermilab's future

Because Fermilab is situated in a rapidly growing community, with new residents arriving continuously, the public engagement will be an ongoing process.

Fermilab already engages the public in a number of ways. There is a general appreciation among the public for the recreational and cultural activities available on the Fermilab site. Outreach to the community on our role in the scientific world is taking place on a number of different levels. These include programs for both teachers and students from local schools at the Lederman Science Education Center, the ongoing Saturday Morning Physics programs, the recently initiated "Meet a Scientist" program, and a variety of environmental activities such as the annual prairie harvest. All of these activities provide opportunities for a personal level of discussion of the current research program, our role within the world of science, and possibilities for the future. However, these current activities may not be enough, especially since participants tend to be neighbors who already possess a positive attitude towards Fermilab, and little is being done to engage the surrounding community in dialog concerning the future of Fermilab.

It is essential that we evaluate our efforts at each step and revise our plans as needed. To be most useful feedback to us should include evaluation by representatives from the constituencies we reach out to, as well as interpretation aided by professionals skilled at evaluation. As the results of the recently completed opinion survey show us, there is a need for us to do better. Among the initiatives that we would recommend for consideration by Fermilab are:

- Incorporate easily accessible information on the nature of the research we do, the tools we use, and possibilities that are under consideration for the future facilities on the new Fermilab website.
- Use results of community opinion survey to create a new Fermilab community outreach plan.
- Conduct a follow-up survey after a few-year period to gauge attitude shifts and the impact of the community outreach plan.
- Create a "Fermilab Future Task Force" to include and involve community members in planning for future facilities.
- Enhance the resources allocated to Fermilab communication efforts, particularly in support of future facilities.

- Strengthen support for Fermilab Education Program (K-12).
- Consider hosting a laboratory open house within the next year and establish this as a periodically recurring event.
- Publicize the existing speakers' bureau with local schools and universities, radio stations and community organizations.
- Identify possibilities for improving accessibility to the Fermilab site.
- Establish contact and communications with the Northeastern Illinois Planning Commission.
- Identify and establish contacts with regional planning commissions to the west of Fermilab

5.6 Bibliography.

1. Peter M. Sandman, "Responding to community Outrage: Strategies for Effective Risk Communication," American Industrial Hygiene Association, 1993.
2. "Social Assessment of High Technology, The SSC in Southeast Michigan," University of Michigan Sociology Department.

CHAPTER 6. POSSIBLE SITINGS OF FUTURE ACCELERATORS

6.1 Electron-Positron Linear Collider

1. Introduction

Over the past 25 years, physicists have used colliding beam accelerators that create hadron-hadron and electron-positron collisions to discover and study new phenomena in elementary-particle physics. Hadron colliders provide good search facilities; they were the first to observe the W and Z bosons and the top quark. Electron-positron colliders provide well-controlled facilities with reduced backgrounds useful for making precision measurements. Scientists have used them to establish QCD and to explore electro-weak phenomena [1]. Progress in particle physics has relied upon the complementary nature of these two types of accelerators. Many recent studies have pointed to a need for the next generation of electron-positron colliders in the 300 GeV to 1.5 TeV region [2-12]. They would allow the physics community to study the properties of particles that are likely to be discovered at the Tevatron and LHC, such as the Higgs boson and supersymmetric particles.

The highest-energy electron-positron machine was LEP II at CERN, a circular accelerator capable of operations at a center-of-mass energy of 210 GeV. Operations of LEP II ceased in the fall of 2000. The disadvantage of the circular machine for electrons is the loss of energy from synchrotron radiation. Such losses require a constant input of large rf power to keep the machine operational. Most accelerator physicists believe that the LEP machine is close to the maximum size imaginable for this type of accelerator. To overcome the disadvantage of synchrotron radiation and achieve higher energies, the Stanford Linear Accelerator Center (SLAC) pioneered the high-energy linear electron-positron accelerator. This work culminated in the Stanford Linear Collider (SLC), where scientists achieved electron-positron collisions at a center-of-mass energy of 100 GeV (see Figure 1).

The success of the SLC has led to the design of even larger linear colliders to achieve energies in the 300 GeV to 1 TeV range. The two most mature designs are the NLC, under development by SLAC using room-temperature accelerating structures [13], and TESLA, under development by the German laboratory, DESY [14], that uses superconducting accelerating cavities. Both machines are currently undergoing intense international R&D. TESLA has recently published a Technical Design Report, including a cost estimate.

Using x-band klystrons, the NLC is a double accelerator system, with one accelerator for electrons and the other for positrons. It has a total length of 24 km, to achieve an energy of 1 TeV [13]. It would have proportionately shorter lengths at lower energies. The luminosity of the machine would be about 10^{34} cm^{-2} sec^{-1} with a high degree of polarization in the lepton beams for detailed studies of new phenomena.

This chapter focuses on the possible siting of a linear collider at Fermilab. Since Fermilab is directly collaborating with SLAC on NLC R&D, the analysis presented here is based on the NLC. However, because physical sizes and requirements are very similar for the NLC and TESLA, nearly all of the information here would apply to either facility.

Figure 1 shows the schematic configuration of the NLC, as it was defined in its year 2000 (CDRO.4) configuration. We discuss below the subsystems as they relate to civil construction, although the technical components such as rf cavities, klystrons and magnets are outside the scope of this document. We discuss the advantages of using the infrastructure already in place at Fermilab and the stability of the geology to provide a steady base to keep the machine components aligned. To understand the advantages and disadvantages of different construction techniques, we have investigated two potential sites. We contrast a deep-tunnel version, the north-south alignment, to a near surface version, the east-west alignment. These sites are representative, not specific, at this time. They do not preclude a deep tunnel in the east-west configuration. However, high population density in the immediate vicinity of Fermilab precludes a near surface north-south implementation.

2. Deep Tunnel North-South Alignment

2.0 Configuration and Salient Design Features

Proposed Facilities

Project spatial and functional criteria were derived from the latest data contained in the NLC Collaboration's CDR 0.4 Conventional Facilities Configuration dating from May, 2000 [15]. Modifications made only as required to support a centralized injection facility are outlined below. We anticipate that most of the technical spaces would be constructed in the Galena Platteville Dolomite stratum at a depth of 450 to 500 feet below the surface.

In the deep-tunnel configuration shown in Fig. 2, the NLC conventional facilities will consist of above- and below-grade utilities and support facilities generally found in high-energy physics laboratories. The Fermilab NLC north-south alignment proposal considers constructing conventional facilities to support a 500-GeV center-of-mass energy machine with potential to expand the conventional facilities in the future to support a 1 TeV machine. We envision constructing the positron and electron sources and injectors centrally on the existing Fermilab site. These produce electrons and positrons at 6 GeV in energy and transport them about 5 km in each direction away from the Fermilab site through a beam transport line of permanent magnets. The beams are bent through 180 degrees and directed back toward Fermilab. Both beams pass through bunch compressors and are accelerated through the main linacs to attain an energy of 250 GeV in each beam. The accelerating structures in the linacs are powered by klystrons mounted in galleries along separate tunnels. Each main linac has a total of 11 klystron galleries (sectors) spaced approximately 1200 feet apart along the machine. At the end of the main linacs, the beams are bent through 20 mradians and eventually collide in the interaction region where a large detector studies the collisions. This design allows future upgrades to the machine either through construction of future tunnel extensions to the north and south with additional linac and klystron galleries, or through replacement of the current rf structures with future replacement technology. Construction of north-south extensions in the initial phase is also an option.

The overall site requires five distinct functional areas: two centrally located injectors, two 5-km long main linacs; and a detector interaction region. The design requires at least one access shaft at each injector as well as one at the far end of the main linacs. The interaction region and detector are located on the Fermilab site north of the existing Village. Given that much of the required infrastructure already exists on the Fermilab site, this siting provides advantages for the campus and the additional support facilities. The north and south ends of the NLC accelerators would each have a surface building, access shaft, and below-grade area to provide access to the bunch compressors at the end of the 8 GeV beam transport lines. Between the detector area and the far ends of the two main linacs would be two underground tunnels: one for housing the beam components and the second for the klystron galleries and services.

Salient Design Features

The intention of the centralized injection is to explore the possible benefits of maximizing the concentration of new infrastructure and utilities in a central campus area. Also, we feel it will reduce the initial startup cost to construct only the tunnel, infrastructure and utility distribution that is required to support the initial 500 GeV machine. Salient design features of the Fermilab N/S centralized injection include:

- Centralized Injection. Sources, pre-linacs and damping rings are located near the power and utility centers reducing distribution losses. Furthermore, transporting the source beams through the main linac tunnels in the reverse direction allows the tunnel lengths to be extended in the future without having to replace the sources.
- Central Cooling. Primary cooling ponds and secondary cooling equipment are located on the existing Fermilab site, with distribution through the support tunnels.

- Central Electrical Power Sub-Station. A new 345 KV / 34.6 KV sub-station is centrally located with electrical distribution through the support tunnels.
- Parallel Support Tunnels. These provide underground "life safety" modeled after transportation tunnel criteria. Radiation shielding is naturally provided by tunnel separation; separate tunnels allow access to support equipment while the beam is running. They also provide the area required for mechanical and electrical support equipment.
- Central Campus. This permits the reuse of existing Fermilab buildings and utilities. Therefore, of the estimated ~ 930,000 sf of lab support and central campus buildings, only 15 percent would require new construction, as 47 percent could be obtained from reworking existing Fermilab buildings, and the final 38 percent could be used with no changes required.
- Minimize access shafts. This assists in managing infiltration, access and construction costs.
- Minimize property acquisition. This can be a major problem for expansion off the Fermilab site. The configuration described here results in a total of about six acres of off-site property acquisition.

2.1 Major Components

<u>*Central Campus*</u>
The central campus would be located on the northeast corner of the Fermilab site. The campus areas would require some new facilities to build, operate, service and maintain the NLC; but many of the needs could be met by augmenting Fermilab's existing structures. Existing functions including auditoriums, cafeteria, conference rooms, offices, industrial buildings and the central computer facility could be used for the experimental program. The Fermilab site also has many of the required services and utilities, such as vehicle maintenance, water and sewage treatment and emergency services. The following table outlines our assumptions for construction of new building spaces and rehabilitation of existing spaces.

Table 1
Fermilab Next Linear Collider North South Alignment
Central Campus
Facilities Assumptions

Facility Type	New Buildings SF	Reused Existing Fermilab Buildings without Modifications SF	Reused Existing Fermilab Building with Modifications SF
Office	15,000	149,000	218,000
Mechanical Assembly	NA	102,000	81,000
Service/Support/ Warehouse	53,000	182,000	122,000
Central Utility Building	25,000	15,000	NA
Control Room	10,000	NA	NA
Comm./Oper. Center	15,000	2,000	NA
TOTAL	118,000	450,000	421,000

Note: The total required square footage is based on the CDR 0.4 criteria [15]. Actual Fermilab building areas may vary to accommodate existing Laboratory buildings.

We anticipate that the access shafts at the far (remote) ends of the main linacs would have surface facilities consisting of 12,000 sf of industrial building and high bay area with 3,000 sf of office space. These satellite facilities may be contained within two sites consisting of three acres each. Minor ventilation shafts would be provided at the midpoints of the main linacs with small HVAC utility structures situated on approximately one acre each.

Main Linac (Beam Housing & Klystron Gallery/Service Enclosure)
Two bored tunnels running parallel to each other would house the main linacs and klystron gallery/service tunnel. The linac beam tunnel contains the rf cavities and is located adjacent to the klystron galleries. They are separated by roughly 20 feet for radiation shielding. The klystron galleries would contain the klystrons, modulators, power supplies, instrumentation and controls. Both tunnels would be constructed using tunnel boring machines (TBM's) and would be lined as necessary to provide a dry environment in the enclosure. The 3,000-sf, 17-foot-high klystron galleries would be constructed at each of the eleven sectors of each linac and would be integral with the service enclosure.

Injectors
Both positron and electron sides of the machine would require an injector facility that includes an injector with a short linac section, damping rings, and a compressor section with a second linac section. The positron injector would also have a pre-damping ring and a positron target. These components would be located slightly north and south (electron and positron, respectively) of the interaction region on the Fermilab site. The 6 GeV electrons and positrons would be transported offsite in opposite directions via permanent magnet beam transport lines in the main linac tunnels to the ends of their respective compression arcs where they would be turned 180 degrees and accelerated back to the interaction region through the Main Linacs. The arcs and damping rings would be constructed with drill and blast techniques, because a TBM cannot turn in the required radius.

Interaction Regions
In the final configuration there may be two interaction regions, one for electron-positron collisions and the second for gamma-gamma collisions. The second has not been included in this design. Each interaction region consists of two structures: a collision hall with support areas lining up with the bore elevations of the below-grade beam lines; and an assembly building at the surface. Each facility would require about 40,000 sf below grade. The lower structure would be constructed with a cast-in-place concrete roof supporting the large mined opening. The grade-level assembly area would be for detector subassembly and would include a heavy crane. Mezzanines would provide areas for computer, control room and office facilities. Other utility areas would house process water systems, electrical power services and air handling equipment. The assembly area would likely be constructed of conventional steel and reinforced concrete construction. Each detector facility includes an access shaft for movement of materials and personnel. This would contain elevators, stairs, crane drops and utility chases.

Conventional Utilities (Domestic Water, Natural Gas, Sanitary Sewer)
The conventional utilities already exist and are available for the Fermilab NLC facilities. This plan calls for extending these utilities along the entire length of the tunnel. The north and south tunnel extension surface facilities would make minimal demands on these utilities.

2.2 Electrical Power

Availability
Electrical power is currently delivered to the Fermilab site by Commonwealth Edison Company's (COMED) 345 KV transmission lines. Transmission Line 11120 is the preferred line between ComEd's Electric Junction and ComEd's Lombard substations. Transmission Line 11119, ComEd's Wayne substation, serves as the emergency line. Each 345 KV transmission line is rated at 1600 amps (956 MVA). COMED has rated Lines 11119 and 11120 each as capable of 1235 MW operation. Peak summertime loads are approximately 625 MW and 1050 MW for Line

11119 and Line 11120, respectively. Therefore, adequate capacity is presently available for the NLC expected load of 300 MW on Line 11119. (The present Fermilab load is approximate 40MVA).

Fermilab's existing Master Substation (MSS) is rated for 266 MVA (4-40/53/66MVA, 345-13.8 KV transformers). However, due to age, the MSS is not anticipated to be available for use on the NLC and will be decommissioned. However, Fermilab's Kautz Road Substation (KSS) has a rated load capacity of 300 MVA (3-40/53.66 MVA, 345-13.8 KV and 1-66/79/99 MVA, 345-13.8 KV transformers) and is served by Line 11119 or Line 11120. KRS was commissioned in 1998 as part of the Main Injector Project and should be available for use by the NLC.

Electrical Power Distribution
The NLC power distribution system requires one new 345-34.5 KV substation with a capacity of 420 MVA. Three 90/115/140 MVA, 345-34.5 KV transformers will be installed as part of the new substation. The transformers will be capable of being powered from either Line 11119 or Line 11120 via 5" 345 KV aluminum bus and 345 KV SF_6 circuit breakers.

Transformer loading (Positron and Electron sides) is assumed as follows:

Injector:	15	5 MVA	34.5-480/277 V
Damping Rings:	4	5 MVA	34.5-480/277 V
Pre-Linac:	12	5 MVA	34.5-480/277 V
Main Linac:	22	5 MVA	34.5-480/277 V
Main Linac:	1	5 MVA	34.5-1.3 KV
Main Linac:	22	5 MVA	34.5-480/277 V (Future)
Beam Delivery:	12	5 MVA	34.5-480/277 V
Interaction:	4	5 MVA	34.5-480/277 V

Transformer secondaries would be connected to 3000A, 35 KV, medium voltage, metal-clad switchgear in a ring bus configuration. Connection to the switchgear would be through the use of 3000A, 35 KV, medium voltage, non-segregated phase bus duct.

The new substation would provide power to the enclosures through the utility shaft in both directions (positron and electron) and would provide all power associated with the technical components of the beam line. Sub-surface beam line components would be powered through the use of 5 MVA, 34.5 KV-480/277 V, double-ended substations with 100 percent backup capability (5 MVA maximum loading) and an automatic transfer scheme located in the sub-grade enclosure. 480/277 V power would then be distributed to beam line components through the use of 600V switchgear and local panel boards or switchboards also located in the sub-grade enclosure.

Conventional power (HVAC, lights, outlets, etc.) in the enclosures would be powered from the existing Kautz Road Substation at 15 KV. Adequate capacity for NLC convention power requirements is available at the KRS in its present configuration as well as providing power for any existing Fermilab conventional loads requiring power at the facility. The existing Main Ring Enclosure would be used for routing of 15 KV cables from the KRS to the NLC shaft area. Installation of the beam line power feeders would be routed in a cable tray system to eliminate the de-rating of the cables and to take advantage of the open-air ratings of the cables.

All surface facilities located at the Fermilab site would be powered from the Kautz Road Substation at 15 KV using the existing Fermilab infrastructure as much as practical. Surface facilities associated with the direct operation of the beam line would be powered from new unit substations similar in configuration to those in the enclosure (double-ended, automatic transfer scheme). Substations not associated with the operation of the beam line would utilize existing Fermilab 1500 KVA, 15KV-480/277 V transformers and 2000 A switchboards. Remote surface facilities not associated with the operation of the beam line would be powered through the use of existing ComEd distribution system.

Emergency Power Electrical Power Distribution
Emergency power for the sub-surface facilities would be distributed at 15 KV as the primary source from the KRS and a second 15 KV source from the ComEd local distribution system. It would not be derived from the source associated with transmission lines 11119 or 11120. An automatic transfer scheme in accordance with the requirements of the Life Safety Code would be implemented.

2.3 Heat Rejection

Project Requirements
The estimated 340 MW heat load would be rejected to existing and newly constructed cooling ponds located on the Fermilab site. Approximately 340 acres comprised of four existing ponds (150 acres) and a new pond or channels (190 acres**)** would be used for heat rejection for the underground accelerator and detector facilities.

System Description
The surface central cooling plant facilities would consist of a central utility building to house the chillers, pumps, heat exchangers, controls, and low conductivity water (LCW) generating equipment. Pumps would draw water from the pond system (ICW), pump it through a centralized cooling plant consisting of industrial grade chillers and return the water to the pond system. The chilled water (CHW) would be circulated through the surface facilities as a primary CHW loop. A pumped secondary CHW loop would be routed to the utility tunnel to serve the multiple temperature LCW circuits and HVAC needs.

The system design would include redundancy considerations using multiple pumps, chillers and heat exchangers to prevent accelerator shutdowns due to equipment failures. The ICW system would be located in and contained in the surface facilities to simplify maintenance and reduce possibilities of tunnel flooding. CHW would be pumped the length of the tunnel using secondary pumps to maintain adequate pressure to the LCW heat exchangers.

Discussion of tunnel pipe sizes, acreage and evaporation
Two 48-inch CHW supply pipes and two 48-inch return headers would carry the CHW from the surface down the central access shaft to the heat exchanger plant at 450 to 500 feet below the surface. Two 30-inch pipes would extend along each direction of the service enclosure tunnel from the heat exchanger plant. These pipe sizes are sized for an anticipated 40° F differential CHW temperature.

The existing Fermilab ponds to be used for this project are currently either not used or are underused as heat rejection ponds for existing facilities. These ponds would be dredged to a minimum six-foot depth to maintain the current drought reserve for Fermilab operation. The ponds would be interconnected with new pond channels to provide a water circulation path. The new 190-acre pond/channel would be approximately 9 feet deep.

The NLC would require 3000 to 4000 acre-feet of water per year due to evaporation from the ponds. This water would be made up by impounding as much of the 20,000 acre-feet of annual precipitation at the FNAL site as reasonably possible, and by capturing the tunnel ground water infiltration. FNAL would continue to supplement the make-up water requirement from the Fox River, provided the river flow is adequate.

2.4 Geology and Tunneling Means and Methods

Site

The bedrock layer under consideration for siting the NLC enclosure is the Galena-Platteville dolomites. The Galena-Platteville dolomites are massive layers of limestone, approximately 300 feet thick in the Fermilab area and about 350 feet below the Fermilab ground surface. Water-bearing sandstone lies below the Galena-Platteville dolomites.

The bedrock layers generally slope down to the east-southeast about seven feet per mile. The only fault in the area is the inactive Sandwich Fault zone, located to the extreme southwest. The Galena-Platteville dolomites are very tight and inhibit water movement.

Site Depth Selection

The Galena-Platteville stratum extends throughout the anticipated north-south length of the machine and is fairly homogeneous. The enclosure would be set as high as possible without compromising structural integrity. This would place the roof of the experimental hall in the Maquoketa shale or Silurian dolomite. Final siting determination would be based on costs, groundwater and vibration considerations. Cost per unit length of tunnel is expected to be higher for the upper shale or dolomite elevations due to the added structural requirements and provisions required to exclude groundwater. Although the upper two strata have the benefit of shallower shaft depth, which would greatly reduce shaft cost, it is not clear that reduced shaft costs would offset the increase in tunneling costs required in the upper two strata.

The greater Fermilab area is geologically and geotechnically a suitable location for siting the proposed NLC. The significant advantages of the geology and the area include: (1) extensive exploration activities that indicate minimal construction risk; (2) favorable geologic conditions that allow flexibility; and (3) extensive rock tunneling experience in the region.

Spoil

We estimate that 2.5 million cubic yards of rock spoil would have to be disposed of for this project. We anticipate that the tunneling subcontractor would be responsible for spoil removal. There are many markets for crushed dolomite in the region, and directly north of the project area is a large existing rock quarry. It might be feasible to transport rock via micro-tunnels and conveyors to this quarry for re-mining. Adding a short spur to the existing railroad system could allow an inexpensive means to transport rock spoil away from the site on the south end of the machine with low impact to the surrounding community. A well-established road system in the area could also be used.

Tunneling Means and Methods

We select means and methods for the excavation of shafts and tunnels for the purposes of cost estimating. While there is some uncertainty, the means and methods used in the majority of the Tunnels and Reservoir Project (TARP) would be employed on the NLC project. Contractor expertise and owned equipment would also have a substantial bearing on the means and methods of choice.

The primary shaft for installation of the tunnel excavation equipment would be driven from the surface using one of several common methods through the overburden. The most common method is vertical lagging with horizontal structural steel rings. Metal plates are installed where charged water-bearing seals are encountered. A cast-in-place or precast permanent liner is later installed through the overburden. Another method used is the sunken caisson, which provides both initial temporary support as well as the final liner. Excavation through the descending rock stratum would be a drill-and-blast operation. Muck would be removed by muck bucket lifted out with a mobile crane. A 20-foot to 30-foot diameter shaft provides ample room for excavation activities. The shaft would be lined with concrete or shotcrete depending on the rock properties. It is anticipated that this primary shaft would be located on the Fermilab site.

The main drifts are made using multiple Tunnel Boring Machines (TBM's) originating from the primary shaft. Using historical data from current TBM excavations in the Chicago area, we consider an advance rate averaging 100 feet per day to be reasonable. Muck would be removed from the tail end of the TBM by either a conveyer or rail muck carts. Lining or panning of the tunnel back and sides is expected only locally where water-producing seams are encountered. The TBM would be backed to the primary shaft location for extraction. We assume drill and blast techniques would be used to construct the proposed detector halls and gallery areas.

The remaining shafts would be raise-bored through the rock using conventional earth retention at the overburden. Twelve to fourteen feet represents the largest reasonable diameter for the raised-bore diameter, and slashing of the perimeter is required to obtain a larger diameter.

2.5 Vibrations

Mechanical Noise as an Issue in Site Selection

The siting of a linear collider along a road or railway right-of-way may be problematic due to the requirement to maintain micron alignment tolerances for many of the main linac components. The effects of mechanical vibrations from railways are a topic for further study. The ongoing studies in the fixed target area at Fermilab and the nearby North Aurora Quarry might be useful. The incorporation of a beam-based feedback that dynamically re-aligns the machine components might help bring these effects under acceptable control [13].

At the Fermilab site, the NLC would be located in a tunnel approximately 450 feet below grade with the overburden consisting in large part of dolomite rock. This is comparable to being located at the surface and parallel to a road running 450 feet away from the linac tunnel. Such local or cultural seismic noise is one source of potential misalignment for the linac. Earth noise, which is seismic noise created by the interaction with wind or sea, is another problem for the machine design. Typically, earth noise lies in frequencies below one Hz, while cultural noise lies above one Hz, though amplitude of ground motion decreases as $1/f^2$ with increasing frequency.

Seismic noise conditions may affect siting decisions, because a plane seismic wave traveling perpendicular to the accelerator has a minimal effect on machine alignment. For example, if we were considering a site near a shoreline, it might be best to align the accelerator parallel to the shore.

One source of mechanical vibration that affects machine alignment comes from devices located within the accelerator tunnel. Sources of mechanical noise include power lines, cooling water pipes and vacuum pumping systems. A siting criterion might include provision for seismic noise to be as small as sources of mechanical noise emanating from within the accelerator tunnel. It is likely, but has not been demonstrated, that surface noise generated above a 450-foot overburden would be small compared to mechanical sources from within the accelerator tunnel.

Vibration Studies

A study for the Illinois siting of the SSC [16] investigated vibrations from truck and railroad traffic, which were considered to be the largest sources of vibration in the region. This investigation monitored truck traffic over an expansion joint of a bridge and the passage of freight trains. Truck traffic showed displacements of 2.9 to 19.3 μm on the bridge abutment. However, 65 feet down and 150 feet horizontal along a rock quarry floor these movements were attenuated 92 to 241 times yielding 0.03 to 0.08 μm. Train traffic displacements on the ground next to the rail line were 1.6 to 4.06 μm. At a site 60 feet down and 190 feet horizontally along the quarry floor the displacements were attenuated 62 to 123 times yielding 0.013 to 0.066 μm.

3. Near Surface E-W Alignment

3.0 Configuration and Salient Design Features

Proposed Facilities
As in the previous section, we derived the NLC project spatial and functional criteria from the CDR 0.4 machine configuration [15]. In this section we consider an east-west alignment for the machine, constructed at or near the surface on a site roughly centered on Illinois Route 23, approximately three miles south of DeKalb, IL and about 30 miles west of the Fermilab campus. In this siting the main housings are constructed in the alluvial soils that make up the surface 50 to 100 feet of geology in this area. Figure 3 shows the basic layout of the machine for this configuration.

We decided to site the machine parallel to an existing linear utility corridor to simplify land acquisition and to provide continuous access to the adjacent 34.6 KV power distribution line. This study assumes that any additional property required to support the NLC project would be evaluated in order to minimize the impact to the public and surrounding communities. We anticipate that much of the estimated 500-foot wide corridor of required property would have to be acquired by the US DOE. We estimate 1200 acres of land would be required for the enclosure corridor and another 1500 acres would be required to construct the five campus areas.

As before, the NLC conventional facilities would consist of above- and below-grade utilities and support facilities generally found in high-energy physics laboratories. The NLC east-west alignment considers constructing conventional facilities to support a 500-GeV center-of-mass machine with the potential to expand the conventional facilities to support a 1-TeV machine. However, unlike the north-south alignment, we anticipate constructing the full length of main linac enclosure (~25 km) to allow for a final 1-TeV machine, although initially only one-half of it would be instrumented. This configuration would have two separate campuses for the positron source and electron sources, approximately 25 km apart. These sources would create electrons and positrons to be transported through opposing, coplanar main linacs that accelerate the beams and direct them to a central interaction region. Each main linac would consist of a total of 22 klystron galleries (sectors) at approximately 1200-foot distances along the machine. At first, only 11 of these sectors would be occupied in order to obtain the 500-GeV center-of-mass machine. This design allows future upgrades to the machine either by outfitting the remaining 11 sectors per main linac, or through replacement of current RF designs with future replacement technology.

The overall site requires five distinct functional areas: positron source campus, electron source campus, west heat rejection facility, east heat rejection facility, and the central campus. The center of the machine is the detector and interaction region that is the main focus of the central campus. We envision that much existing infrastructure on the Fermilab site 30 miles to the east could used for support facilities and would not require duplication at the NLC central campus.

Salient Design Features
The configuration for the east-west alignment involves using near-surface construction techniques such as open-cut excavation, braced slurry wall excavation and soft-bore tunneling to construct the required below-grade enclosures. Salient design features of the east-west study include:

- Zoned heat rejection. Three areas of cooling ponds and secondary cooling equipment are located along the alignment consisting of a total of 300 acres of surface water and associated equipment to produce the required chilled water. Distribution is accomplished through direct buried HDPE piping.
- Central Electrical Power Sub-Station. A centrally located new 345 KV / 34.6 KV sub-station would be required with electrical distribution provided through a linear near-surface duct bank.

- One Enclosure. "Life-safety" requirements have been modeled from existing Fermilab criteria. Radiation shielding is provided by earthen cover, berms or locally placed steel. Egress is provided through stairwells at spacing similar to that used in the Main Injector Project at Fermilab.
- Central Campus. It is anticipated that existing Fermilab facilities can be used in support of the NLC central campus. Of the required ~ 930,000 sf of Lab support and Central Campus Buildings, only 42 percent would require new construction, as 20 percent of the required space could be obtained from reworking existing Fermilab buildings, and the final 38 percent could be used with no changes required.

3.1 Major Components

Campus

Five campuses are anticipated for the NLC east-west alignment. The central campus would be located near Illinois Route 23. The campus areas would require new facilities to build, operate, service and maintain the NLC interaction region. Although specific structures would be needed for the project, many of the needs could be met by augmenting Fermilab's existing structures. Common functions include auditoriums, cafeteria, conference rooms, offices, industrial buildings and a central computer facility for the experimental program. The following table outlines our assumptions for construction of new building spaces and rehabilitation of existing spaces.

Table 2
Fermilab Next Linear Collider East-West Alignment
Central Campus
Facilities Assumptions

Facility Type	**New Buildings SF**	**Reused Existing Fermilab Buildings without Modifications SF**	**Reused Existing Fermilab Building with Modifications SF**
Office	123,500	148,900	107,500
Mechanical Assembly	80,000	0	101,635
Service/Support/ Warehouse	88,000	82,040	15,000
Central Utility Building	100,000	15,800	107,500
Control Room	10,000	0	0
Comm./Oper. Center	17,000	1,950	0
TOTAL	418,000	248,690	209,150

Note: Total required square footage is based on the CDR 0.4 [15]. Actual Fermilab building areas may vary to accommodate existing Laboratory buildings.

Main Linacs and Klystron Galleries

The main linacs would involve the construction of below-grade enclosures similar in size and function to those currently used at Fermilab. They would require a combination of cast-in-place and precast concrete construction in order to provide the approximately 14' by 14' cross-sectional dimension of the enclosure that would house the main linac rf cavities, focusing magnets, and wave guides. The klystron galleries would be semi-surface buildings placed approximately every 1200 feet along the main linacs to house the klystrons, modulators, power supplies, instrumentation and controls. The klystrons distribute RF to the main linacs through multiple duct-like wave guides.

Injectors
Both the positron and electron sides of the machine require an injector facility that includes an injector with a short linac section, damping rings and a compressor section with a second linac section. The positron injector would also have a pre-damping ring and a positron target. These components would be located at the extreme ends of the main linacs and would be constructed with open-cut construction and surface buildings similar to those of the main linac klystron galleries.

Interaction Regions
As before, we envision two interaction regions, although only one is considered in this report. Each interaction region consists of two structures: an above-grade assembly building with a below-grade, or near-grade, collision hall, lining up with the elevations of the main linac beam lines. The collision hall would require about 40,000 sf, and would be constructed with cast-in-place concrete much like Fermilab's existing collision halls, D0 and CDF, at the Tevatron. The grade-level assembly area would be used for detector subassembly and would include a heavy crane. Mezzanines would provide areas for computer, control room and office facilities. Other utility areas would house process water systems, electrical power services and air handling equipment. The assembly area would be constructed of conventional steel and reinforced concrete construction.

Conventional utilities (Domestic water, natural gas, sanitary sewer)
Conventional utilities do not exist at the east-west site and are anticipated to be constructed with this project or adapted from the local municipal systems.

3.2 Electrical Power

Availability
We understand the existing 345 KV line parallel to the project is currently at its peak demand and would therefore not be available to feed this project. We assume a new 345 KV line would be constructed on this utility easement for the NLC project.

Electrical Power Distribution
The NLC power distribution system includes two, new 345-34.5 KV substations with a capacity of 420 MVA. Three (3) 90/115/140 MVA, 345-34.5 KV transformers will be installed as part of the new substations. The transformers will be capable of being powered from either Line (existing or proposed) via 5", 345 KV aluminum bus and 345 KV, SF_6 circuit breakers.

Transformer loading (Positron and Electron) is assumed as follows:

Injector:	15	5 MVA	34.5-480/277 V
Damping Rings:	4	5 MVA	34.5-480/277 V
Pre-Linac:	12	5 MVA	34.5-480/277 V
Main Linac:	22	5 MVA	34.5-480/277 V
Main Linac:	1	5 MVA	34.5-1.3 KV
Main Linac:	22	5 MVA	34.5-480/277 V
Beam Delivery:	12	5 MVA	34.5-480/277 V
Interaction:	4	5 MVA	34.5-480/277 V

Transformer secondaries would be connected to 3000 A, 35 KV, medium voltage, metal-clad switchgear in a ring bus configuration. Connection to the switchgear would be through the use of 3000 A, 35 KV, medium voltage, non-segregated phase bus duct.

The new substations would provide power to the enclosures through the utility shaft in both directions (positron and electron) and would provide all power associated with the technical components of the beam line.

Sub-surface beam line components are to be powered through the use of 5 MVA, 34.5 KV-480/277 V, double-ended substations with 100 percent backup capability (5 MVA maximum loading) and an automatic transfer scheme located at the surface at each RF gallery. 480/277 V power would then be distributed to beam line components through the use of 600 V switchgear and local panel boards or switchboards also located at the surface.

Conventional power (HVAC, lights, outlets, etc.) in the enclosure would be powered from local 34.5 KV-480/277 V transformers at each access building or RF gallery.

3.3 Heat Rejection

Project Requirements
The estimated 340-MW heat load would be rejected to newly constructed cooling ponds located along the site. Approximately 300 acres composed of three proposed ponds would be used for heat rejection for the detector facility and the underground facilities. The new ponds would be approximately nine feet deep.

System Description

The system requirements would be the same as those listed for the north-south alignment.

Discussion of tunnel pipe sizes, acreage and evaporation
A 24"-CHW supply pipe and two return pipes would carry the CHW from the cooling plant facilities to the heat exchanger plants at each klystron gallery service building. These pipe sizes are sized for a 40°F differential CHW temperature.

The NLC would require 3000 to 4000 acre-feet of water per year due to evaporation from the ponds. This water would be made up by impounding annual precipitation. We would supplement the make-up water requirement from local rivers and streams.

3.4 Geology and Tunneling Means and Methods

Site
We propose to site the east-west orientation within the glacial overburden or alluvial soils that exist in this area from 50 to 100 feet below the surface. We anticipate that the orientation of the linacs would be in a straight configuration, rather than following the earth. Therefore, the cover over the enclosure would vary from 24 to 90 feet. This dictates the use of a variety of excavation techniques for the enclosure construction as outlined in the means and methods below.

Spoil
To minimize cost, spoil will be kept to a minimum. We anticipate the reuse of most of the excavated materials in the earthen berms required for the estimated 24 feet of passive radiation shielding. We approximate between 10,000 and 50,000 cubic yards of material may have to be stockpiled on the site.

Enclosure Construction Means and Methods
While there is some uncertainty it is highly likely that the means and methods for the excavation of the majority of the tunnels used in the main linacs would be the same as used for the Main Injector Project at Fermilab. However, contractor expertise and owned equipment would also have a substantial bearing on the means and methods of choice.

The excavations for enclosure construction would most likely be prepared by one of the following three methods. Method One is conventional cut and cover construction like that used for the majority of the enclosures at the existing Fermilab site. Method Two is slurry wall construction involving the excavation of two parallel trenches about 16 feet apart and 50 to 60 feet deep. The trenches are filled with a bentonite slurry to maintain integrity. A reinforced concrete wall is then constructed in the trenches. Finally, the soil between the slurry walls is excavated and the enclosure is constructed between the slurry walls at the required depth. Method Three is soft-bore tunneling. This involves constructing a circular cast-in-place or precast-concrete-lined-tunnel by tunneling and jacking. This can be accomplished by several means including shielding and slipforming. The lining forms the final usable enclosure space.

Method One will be assumed to be appropriate to a depth of 35 feet. Method Two will be assumed to be appropriate from 35 to 50 feet in depth. Method Three would be used in depths exceeding 50 feet. Where needed, shafts of various sizes would be constructed from the enclosure to surface buildings.

3.5 Vibrations

Mechanical Noise as an Issue in site Selection:
The siting of a linear collider along a road or railway right-of-way may be problematic due to the requirement to maintain micron alignment tolerances for many of the main linac components. The effects of mechanical vibrations from railways is a topic for further study. The ongoing studies being performed in the fixed target area and the nearby North Aurora Tunnel may be useful. We do not know whether it would be a problem or not, and the incorporation of beam-based feedback could bring these effects under acceptable control. Earth noise, seismic noise created by the interaction with wind or sea, is another form of noise that can pose a problem for the machine design. Typically, earth noise lies in frequencies below 1 Hz, while cultural noise lies above 1 Hz, with an amplitude that decreases as $1/f^2$ with frequency.

Seismic noise and mechanical vibrations would be similar to those for the north-south alignment.

References

[1] Physics and Technology of the Next Linear Collider, SLAC-Report-485; BNL-52-502; Fermilab-Pub-96/112; LBNL-Pub-5425; UCRL-ID-124160.

[2] C. Ahn et al. SLAC -Report-329 (1988).

[3] Proc. of the Workshop on Physics at Future Accelerators (La Thuile), CERN, Geneva (1987).

[4] Proc. of the 1988 DPF Summer Study: Snowmass '88, High Energy Physics in the 1990s, E. L. Berger, ed., Snowmasss, CO (1988).

[5] Proc. of the First Workshop on Japan Linear Collider (JLC I), S. Kawabata, ed., KEK (1989).

[6] Proc. of the 1990 DPF Summer Study: Snowmass '90, Research Directions for the Decade, F. Gilman, ed., Snowmasss, CO (1990).

[7] Proc. of the Second Workshop on Japan Linear Collider (JLC II), S. Kawabata, KEK (1990).

[8] Workshop on Electron-Positron Collisions at 500 GeV: The Physics Potential, DESY (1990).

[9] Proc. of the First International Workshop on Physics and Experiments with Linear Colliders, R. Orava, ed., Saariselka, Finland (1991).

[10] Proc. of the Second International Workshop on Physics and Experiments with Linear Colliders, F. Harris et al., eds., Waikoloa, Hawaii (1993).

[11] Proc. of the Third International Workshop on Physics and Experiments with Linear Colliders, Iwate, Japan (1995).

[12] U.S. Department of Energy MEPAP Subpanel Report, "Planning for the Future of US High Energy Physics," F. Gilman (Chair, (1998).

[13] Zero-Order Design Report for the Next Linear Collider. SLAC-Report-474; LBNL-5424; UCRL-ID-124161; UC-414.

[14] Talk presented by R. Brinkman at the VIII International Workshop on Linear Colliders (LC99, Frasenti, Italy, Oct. 21-26, 1999)

[15] NLC Lehman Doe Review (May, 1999); and subsequent modifications as per NLC-CDR-0.4 criteria (May, 2000).

[16] Robert A. Bauer and David L. Gross, Geology of the Greater Fermilab Region, Illinois State Geological Survey

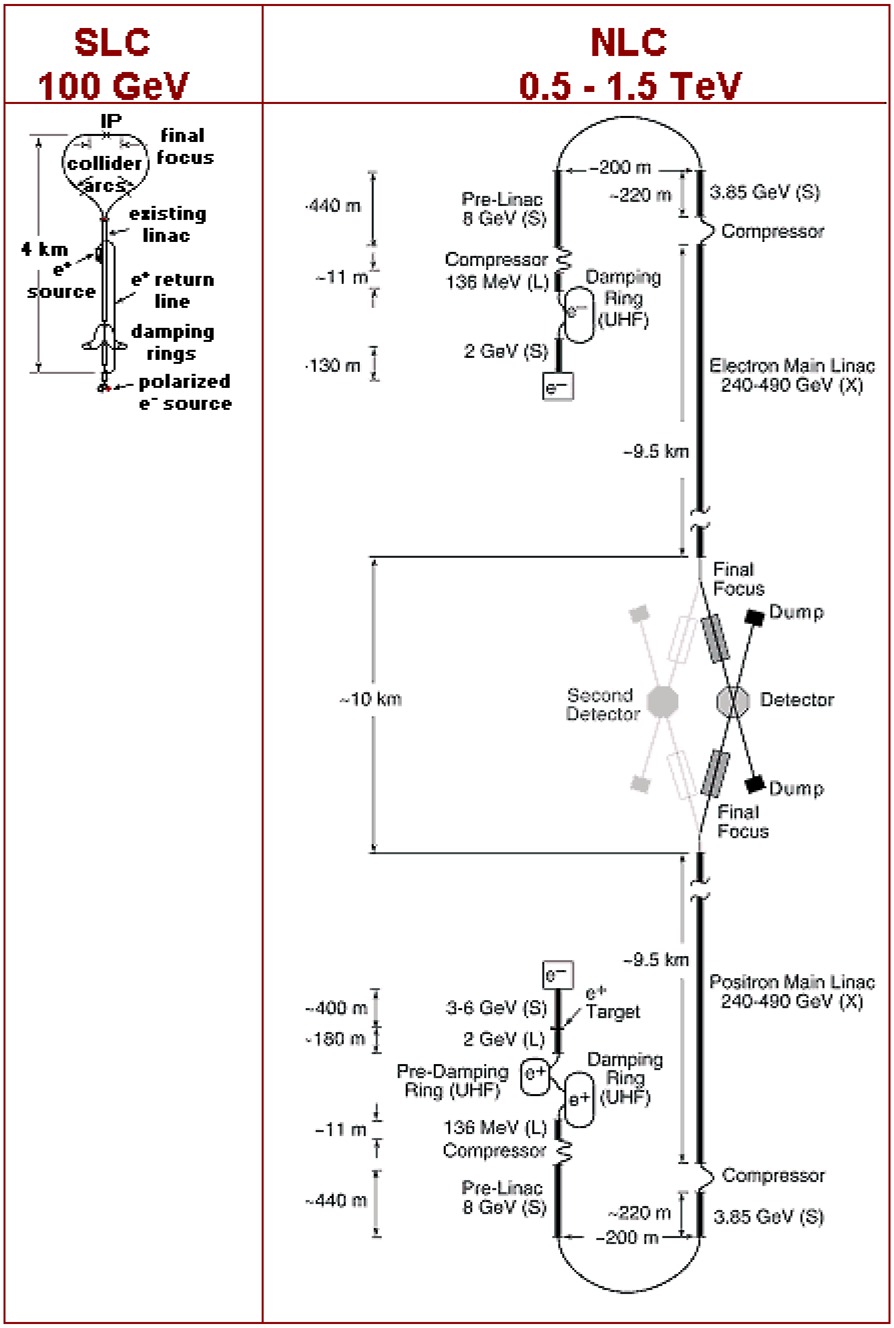


Figure 1 Schematic configuration of NLC

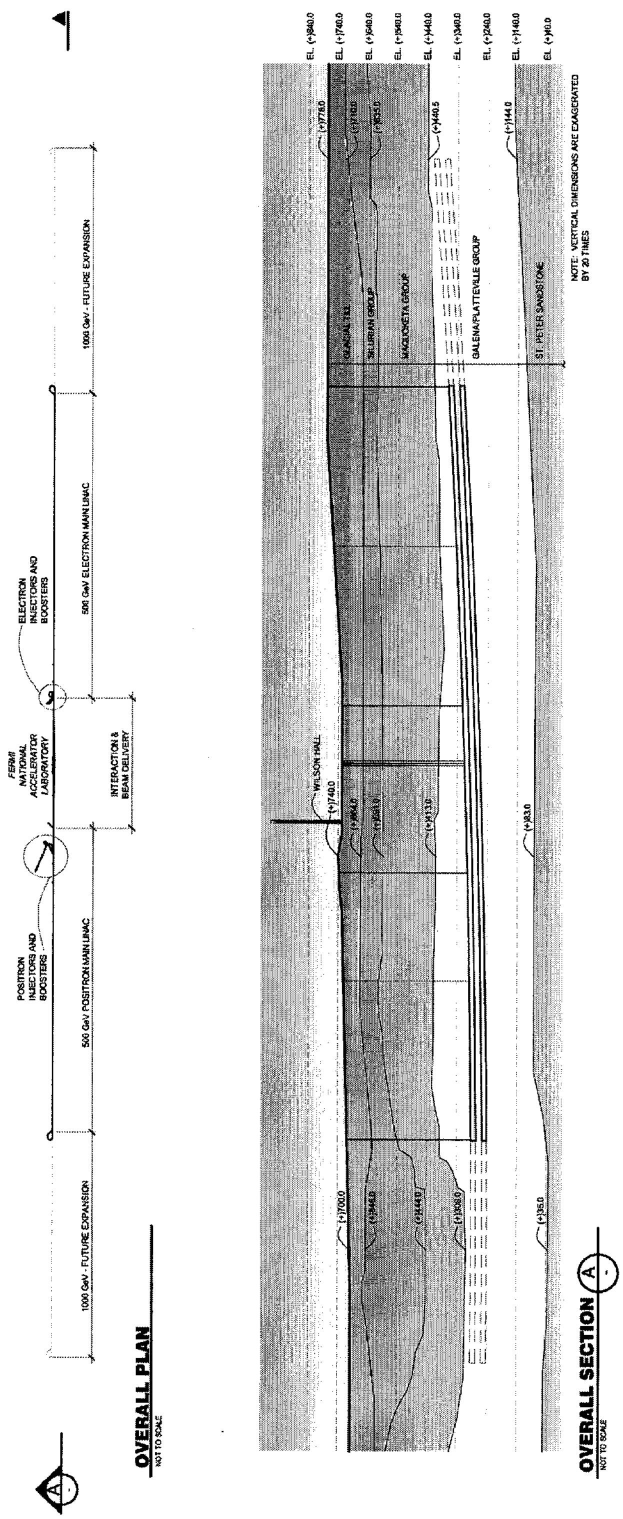


Figure 2 : Cross-section of a north-south oriented siting for a linear collider. This orientation would traverse the Fermilab site, most probably in the vicinity of the east side power corridor.

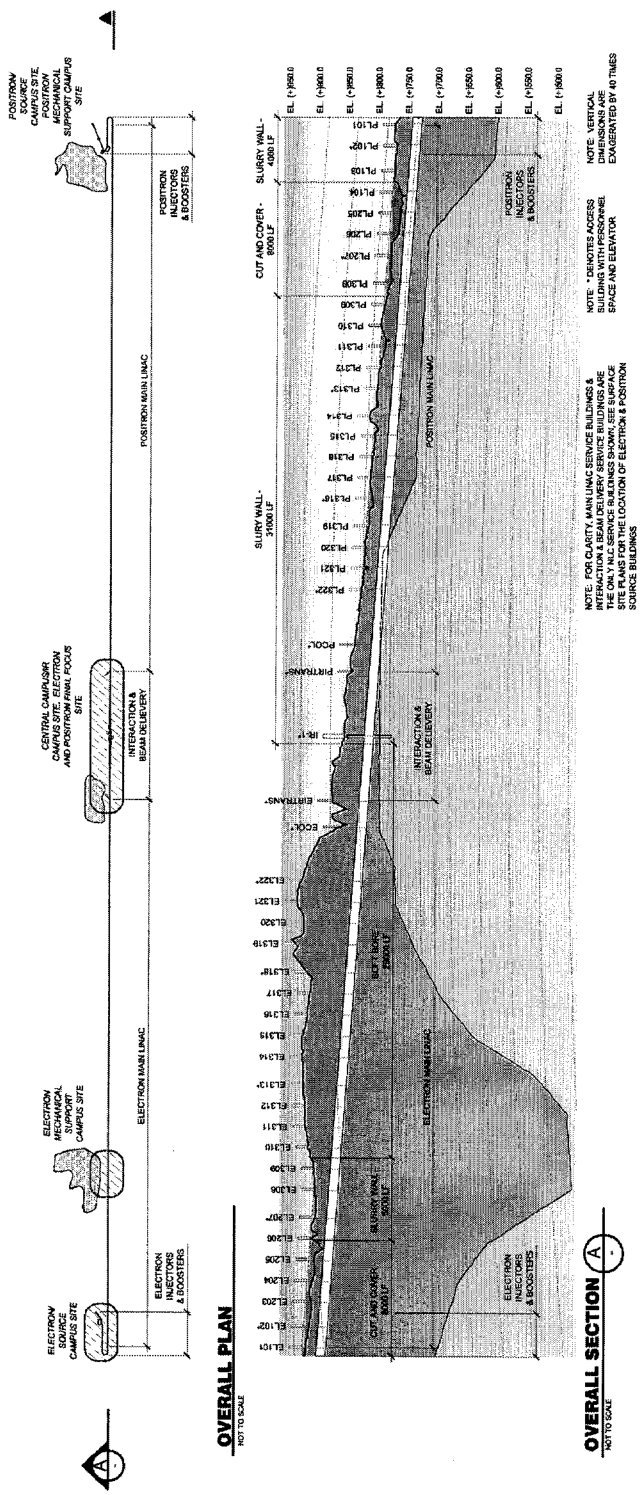


Figure 3 : Cross-section of a near-surface east-west oriented siting for a linear collider. This orientation would lie approximately 20 miles to the west of Fermilab, most likely in close proximity to the power transmission lines south of Interstate Route 88.

6.2 Neutrino Factory

1. Neutrino Factories based on Muon Storage Rings

1.1 Introduction

We base much of this section on the recent neutrino factory study 1 report: [1] "Feasibility of a Neutrino Source Based on a Muon Storage Ring". The feasibility study report includes a chapter on the required conventional facilities, which focuses very much on the specific design studied. We base the following description on a somewhat broader approach and consider other possible candidates for future Neutrino Source designs.

1.2 Description of the Program and the Facility

Using a muon storage ring to provide an intense neutrino beam would greatly enhance the future neutrino physics program. Classical neutrino sources consist of a proton beam incident on a pion production target, followed by a long pion decay channel, producing a $\bar{\nu}_\mu$ or ν_μ beam. In a muon storage ring, the muons circulate after injection until they decay. If the ring has straight sections, a fraction of the muons will decay in the straight sections, to produce an intense, well-collimated beam containing ν_e (or $\bar{\nu}_e$) as well as $\bar{\nu}_\mu$ (or ν_μ). It is the presence of electron neutrinos and antineutrinos in the beam that provides a greatly enhanced neutrino oscillation physics program. It should be noted that neutrino oscillations are a newly observed phenomenon that provides us with the first concrete evidence for physics beyond the Standard Model. If the muon beam divergence in the straight section is small compared to the typical muon decay angle, the opening angle of the neutrino beam is completely dominated by the decay kinematics, and for muons of a given energy, the beam divergence is ~$1/\gamma$.

- Energy of the Storage Ring is < 50 GeV
- Number of neutrinos is 10^{19}-10^{21} per year
- Capability to switch between μ^+ and μ^-
- Baseline length between 2000 –6000 km

Table 1: Set of approximate design parameters for a Neutrino Source Based on a Muon Storage Ring.

A muon storage ring used to produce very intense and flavor-pure neutrino beams will most likely be the first application of a future intense muon source. After being generated from pion decay and cooled in an ionization cooling channel, the muon beam is accelerated and injected into a storage ring with long straight sections. The muons decaying in the straight sections generate the

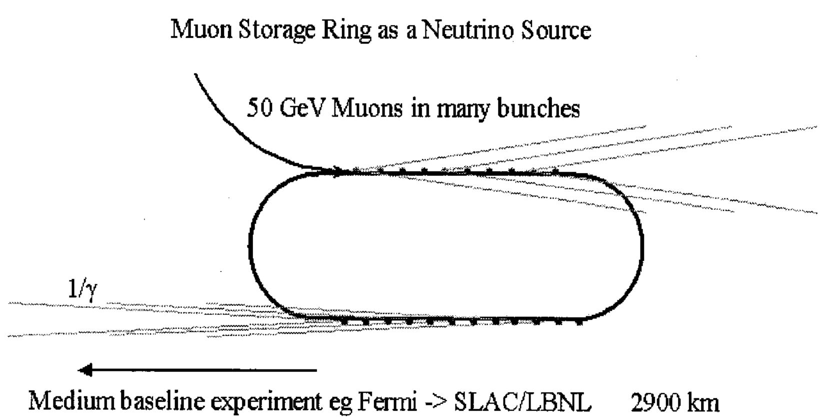


Figure 1: Sketch of a racetrack-shaped muon storage ring indicating the opening angle of the neutrino beam dominated by only kinematics on one side ($1/\gamma$) and with a contribution from the divergence of the muon beam ($\propto 1/\sqrt{\beta_\perp}$) on the other side.

neutrino beam. The idea of producing a neutrino beam using a storage ring has been described many times. The initial idea was to inject pions into the ring, which then captures muons from pion decay. The decaying muons then provide the desired electron neutrino beam. However, this method does not produce a sufficiently intense neutrino beam. Recently, following the progress made on ionization cooling concepts within the Neutrino Factory and Muon Collider Collaboration [2], it has been proposed [3] to use a Muon Collider type muon source, and inject the accelerated muons directly into the storage ring. The resulting Neutrino Factory would produce a very intense neutrino beam. With a new proton driver and a target that could withstand the associated power density and intense radiation, the source would produce enough pions, and hence muons, to provide $2x10^{20}$ muon decays per year or more in the straight sections of the storage ring. To achieve this goal, very efficient and large- aperture focusing solenoids and low-frequency rf accelerating systems must be developed for the ionization cooling channel. The initial transverse emittance of the captured muons must be reduced by about a factor of 10 in both transverse dimensions before the muons can be accelerated to an energy of several tens of GeV. Longitudinal phase space cooling (emittance exchange) will almost certainly not be required. These requirements are less demanding than for a muon collider that will require emittance exchange and a different technical approach. Given an intensity goal of $2x10^{20}$ muons per year decaying in one straight section, we have made an attempt to investigate the overall technical feasibility of such a facility. Table 1 gives a typical set of parameters for a Neutrino Factory neutrino source.

In the simple version of a racetrack-shaped storage ring with two long straight sections considered in the feasibility study (Figure 1), more than one-third of the muons would decay in each straight section. Given the large variety of possibilities for medium (~500 km), long (~3000 km) and very long baseline (>7000 km) experiments, and the dependence of the technical layout of the storage ring on the baseline, a specific choice was made for study 1 (= 3000 km). In addition, we chose a specific set of accelerator parameters based on the physics goals known at the time of the study, which are described in more detail in Ref. [4].

To achieve a higher-intensity, brighter muon beam requires a way of producing a large number of muons per second and a method of cooling the muons. This leads to some real-estate requirements for the target region, where a proton beam of up to 4 MW (cw power) has to be dumped on a comparatively small target, which is located in a high field solenoid (~18T to 20T). The target is followed by a 50-m decay channel ($\pi \Rightarrow \mu$ conversion). This is followed by 100 meters of induction linac to reduce the energy spread of the muon beam. Ionization cooling, the basic concept for reducing the transverse emittance of the muon beam, follows in a 150-meter-long low-frequency linac with a klystron gallery on top. At this point the muon beam still has a momentum of ~180 MeV/c and must be accelerated, requiring a cascade of accelerating recirculating linacs. For the case shown here, this cascade starts with a 3 GeV, 200 MHz super-conducting linac at a length of ~400 m. The 3 GeV beam is injected into a 4-turn recirculating linac operating with 200 MHz super-conducting rf and finally a 5-turn recirculating linac operating at 400 MHz superconducting rf, which finally injects the 50 GeV muon beam into the storage ring.

1.3 Basis for the Accelerator Facility Layout

Table 1 shows the final list of parameters for study 1. This table, together with a number of assumption and boundary condition that are described in detail in Ref. [1], define the technical requirements of the accelerator complex.

The footprint of the Neutrino Factory facility is comparatively small and fits easily on the Fermilab site. Figure 2 shows a generic sketch of the accelerator facility, drawn to scale. This figure shows the logical relationships between the various subsystems. The largest subsystems are the accelerating linac in the cooling channel, the superconducting linac after the cooling channel, and the recirculating accelerators (RLA1 and RLA2). The total area required in order to provide a 50 GeV muon beam to a storage ring is approximately 1.0×2.0 km^2. A more elaborate, site-specific picture is shown later where, using minimal deviations from the logical layout, we have integrated the facility into the Fermilab site. We have placed the proton driver near the Main Injector, and the rest of the facility easily fits inside the Tevatron ring.

The basic principle that leads to the generic (logical) layout is that bending between the different subsystems should be minimized. This will minimize the muon losses due to the large transverse emittance that must be transported. In our design, we also require the same number of passes through each linac of the RLAs . This is to make the beam loading equal on both sides of each RLA, which ensures identical rf system requirements for both sides. Coming out of the last RLA, the muon beam would be gently bent downward into the storage ring tunnel and injected into the straight section pointing to the long-baseline experiment. A remarkable result of this layout is that the direction in which the proton beam hits the target defines the natural direction of the neutrino beam going to the experiment. Therefore, once the location of the detector is fixed, the layout is constrained, or one of the optimizing conditions must be given up, thereby increasing cost or decreasing performance. This might be the case if Neutrino Factory construction is staged so that an entry level Neutrino Source has only one RLA, and hence lower muon energy.

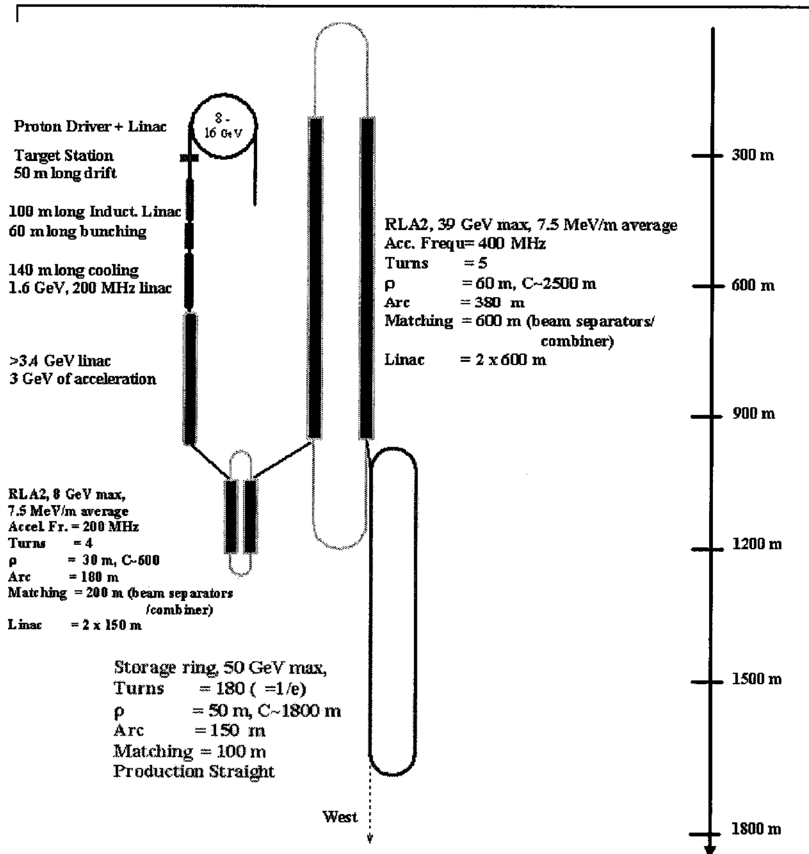


Figure 2: Footprint (~to scale) of the entire facility

2. Required Conventional Facilities for a Neutrino Factory

2.1 Introduction The conventional facilities for the proposed Neutrino Factory include all necessary civil construction components required to house the beam facilities and on-site physics detectors including below-grade enclosures, access shafts, halls and surface support buildings. In addition, conventional facilities include site improvements such as grading, roadways, utilities, heat rejection facilities such as cryogenic plants and cooling ponds, and high voltage electrical supply. Although designed specifically for the Fermilab site, this is an almost site-independent description of the required infrastructure for such a facility. We have included some of the existing infrastructure at Fermilab in the preliminary design. Under the assumption that the existing proton physics program would probably not be viable at the time when a Neutrino Factory would be ready for operation, the Fermilab infrastructure including roadways, utilities, heat rejection facilities, high voltage electrical supply, office buildings and mechanical support facilities would be available for use by the Neutrino Factory facility. The following pages describe the preliminary conceptual design for the conventional facilities portion of the proposed Neutrino Factory at the Fermilab site.

2.2 Description of the Proposed Conventional Facilities

The technical components of the facility include the 16 GeV booster, target hall, decay drift channel, induction linac, bunching, cooling, 3 GeV linac, recirculating linear accelerators 1 and 2 (RLA 1 and RLA 2), and finally the muon storage ring (MuSR), which houses beamline components to direct the neutrino beam to its final destination. We derived several layouts for the Fermilab site. Constraints for these layouts included the size of the elements and their respective adjacencies, site radiation requirements, existing environmentally sensitive areas and existing developed areas. We avoided existing developed areas and wetlands to minimize cost and environmental impact.

The layout shown in Figure 3 meets all the criteria mentioned above and is relatively close to existing cooling ponds and electrical distribution systems. This layout utilizes the existing 400 MeV H-minus linac, includes a new 16 GeV booster around the existing Antiproton Source, includes a beamline to carry 16 GeV protons to the existing Main Ring beam enclosure, and eventually to the infield of the Main Ring (currently undeveloped) where the remaining machine elements would be constructed. We anticipate improving and expanding the existing Fermilab infrastructure as it relates to mechanical and electrical systems, grading, paving and parking. The following sections outline the current required improvements for each.

2.3 Mechanical Systems

We anticipate a total cooling load of approximately 150 MW for the proposed facility. We assume 80 percent (120 MW) is technical component power and 20 percent (30 MW) is conventional power for cooling, lights, etc. In addition, a large fraction of the technical component cooling is chilled, especially for the cryogenic facilities, and roughly 25 percent is exchanged pond cooling (95LCW). At the 150 MW level, pond-water circuiting would not interfere with other current operations on site, if they were to remain. Pond-water cooling would be circuited through equipment in a central cooling plant (CCP) and spray discharged into Lake Logo, on the east side of RLA2.

2.4 Electrical Systems

The anticipated electrical load required for this facility is 150 MW. This is based entirely on the technical description of the report mentioned before. It would require approximately 30 MW for the proton synchrotron, 15 MW for the target station, 45 MW for the cooling, and 60 MW for the accelerating systems. A large advantage is the small footprint, which facilitates a compact electrical distribution.

2.5 Grading

We anticipate using earthen berms for radiation shielding above most cut and cover enclosures. Fermilab currently has over seven miles of earth-shielded cut and cover enclosures of a similar type. The design would also require general site grading for drainage and wetland mitigation. The project would attempt to balance cut and fill volumes to minimize earth excavation and hauling costs. Apart from the target hall building, where the 1.5-4 MW proton beam is dumped, the project would require no substantial shielding. Even the high-energy muons do not interact strongly; therefore a few meters of earth shielding lateral to the beam is sufficient. This is not true for the target hall, and is also not quite true for the decay channel, which requires additional shielding because of the substantial number of neutrons generated close to the target. Also for the two linear extensions of the straight sections of the muon storage ring, where the neutrino beams exits the storage ring enclosure, the design must take into account radiation from nuclear interactions of the neutrinos with matter. Within a cone of opening angle of $1/\gamma$ (= 0.002 mrad at 50 GeV), if there are 2×10^{20} μ decays per straight-section, the unlimited occupancy limit of 100 mrem per 2×10^{7} sec year is satisfied at distances larger than ~1.5 km.

Figure 7 shows the boundaries applied to the Fermilab site that could enclose Neutrino Factories of two different energies, so that specified annual limits on radiation dose equivalent that could potentially be received by members of the public are met. At the western boundary of these zones, the specified maximum annual dose equivalent would be found deep underground where no one would be present. For the chosen eastern boundaries of these zones, beyond the Fermilab site the specified maximum annual dose equivalent would be found at an elevation of 200 meters above the surface, likewise unoccupied space. Near the ground surface, the annual dose equivalent due to operation of this facility would be effectively zero at all locations beyond the present Fermilab site.

2.6 Surface Buildings

Additional office or manufacturing buildings would not be required. However, new beamline support buildings and klystron galleries above the enclosures would be necessary. Figure 3 shows a site overview of these surface buildings with a more detailed sketch of the klystron gallery for the cooling channel. Figure 4 and Figure 5 show the klystron gallery in more detail. Because of the high density of low frequency klystrons delivering high peak power significant space would be required. We estimate that as much as 300,000 sf of these low-rise industrial type buildings would be necessary for the total facility. Below grade facilities for the study 1 design include cut and cover type enclosures and sloping enclosures constructed with tunneling technology. Another building of specific interest is the proton target hall, where up to 4 MW of average proton beam power would be dumped. This produces a very radioactive environment, and requires a specific design for shielding. The target hall design is similar to the design of the Spallation Neutron Source (Oak Ridge, Tennessee) target hall, and a sketch is shown in Figure 6.

The estimated 18,500 lineal feet of near-surface enclosures constructed with the cut and cover construction would vary in width from 10 feet in the 16 GeV Booster beam enclosure to as much as 60 feet in the RLA arcs. Heights would range from 8 to 10 feet. These underground areas will be used to house beamline elements, starting with the 400 MeV H-minus beamline and ending with the extraction of the muon beam from the second recirculating linac. Earthen cover of between 15 and 25 feet would be typical for these enclosures. The majority of this accelerator complex would be constructed at or near the surface with cut and cover construction. Sloping enclosures for the Muon Storage Ring (MuSR) would be constructed with methods including cut and cover at the shallow arc, soft tunneling in the glacial moraines and drill and blast methods in the lower shale and dolomite rock. With our design the MuSR consists of 5800 lineal feet of enclosure sloping at 13 percent pointed nearly due west to deliver Neutrinos to a detector located somewhere on the West Coast of the United States. We expect tunnel enclosure cross sections for the proposed MuSR to be approximately 10' wide and 13' high. We have chosen the length of the tunnel to maximize the neutrino yield in the far detector. The maximum possible fraction of muons that could decay in one straight section is 50 percent. The study 1 design achieves about 39 percent, which requires maximizing the length of the straight sections. With a total vertical descent of ~200 meters available, and a ring circumference of ~2 km, this requires superconducting dipoles to minimize the arc lengths.

The details of the surface buildings, and especially the enclosures for the storage ring, would depend very much on the details of the design and the parameters picked for the neutrino source. The example described here is closer to the ultimate design performance one would like to achieve. Building the facility in stages would relieve certain constraints and make it easier. If, on the other hand, multiple long-baseline experiments will have to be served with one storage ring, a much more complicated design (Triangular shapes, 8- shapes etc) would be necessary. In this case much larger slopes would have to be made (up to 45 degree), and vertical beamline installations with a storage ring plane rotated with respect to the center might be needed.

3. Summary

We have presented a very general description of a Neutrino Factory that includes a summary of all the major subsystems that are required. The boundary conditions for the construction of the facility we have described are taken from a very specific design described in a six-month study of the feasibility of a neutrino source based on a muon storage ring. Although several options are currently being investigated, we chose the simplest one, which uses a racetrack storage ring. The final decision on the required energy of the storage ring will lead to either one- or tw0-stage RLA designs. For all the other subsystems, the basic layout will probably not significantly change.

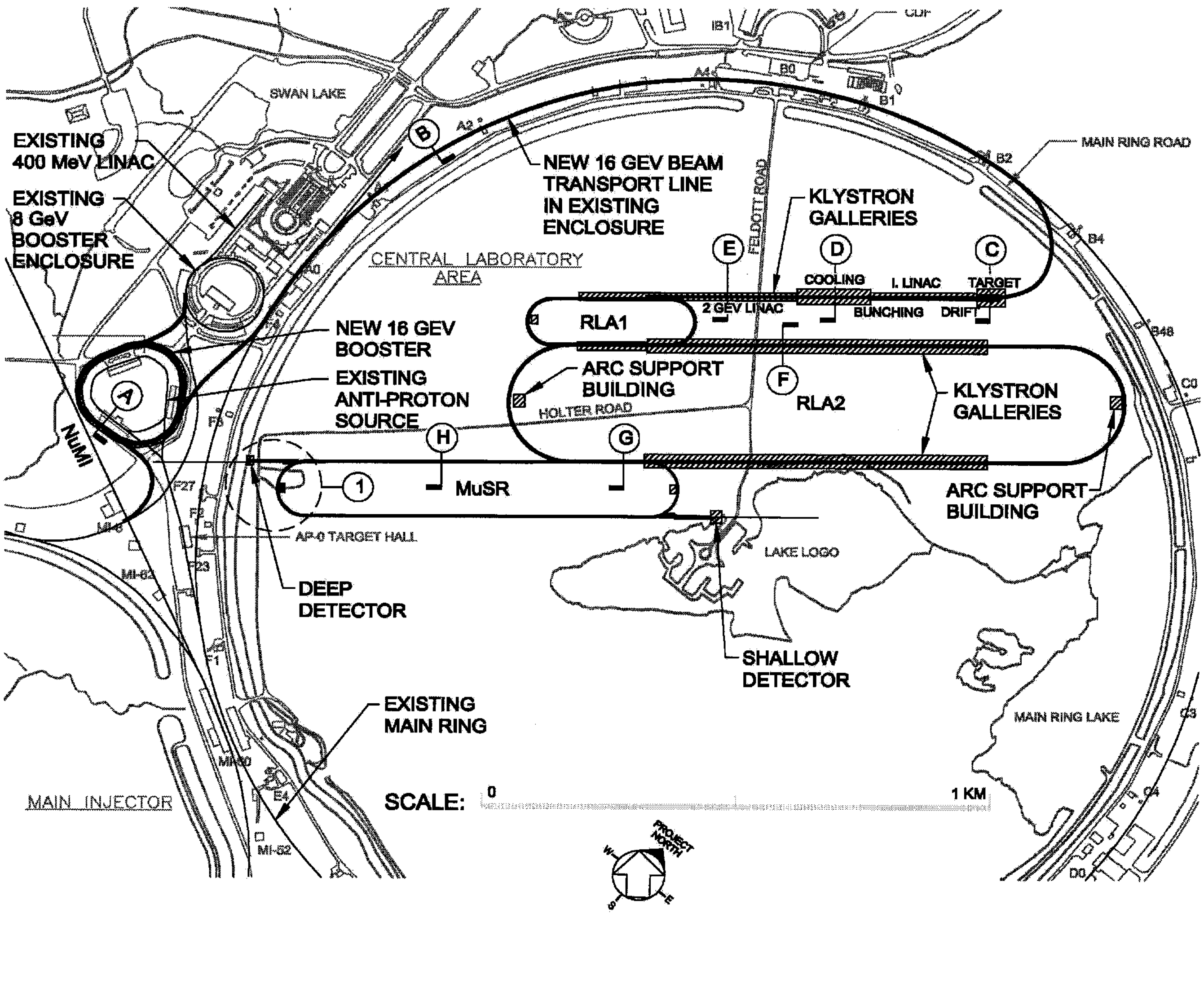


Figure 2: Sketch of the Neutrino Factory layout on the Fermilab site. The sections (A through F) and details (1 and 2) are shown in the figures, which follow. The hatched areas indicate new surface buildings.

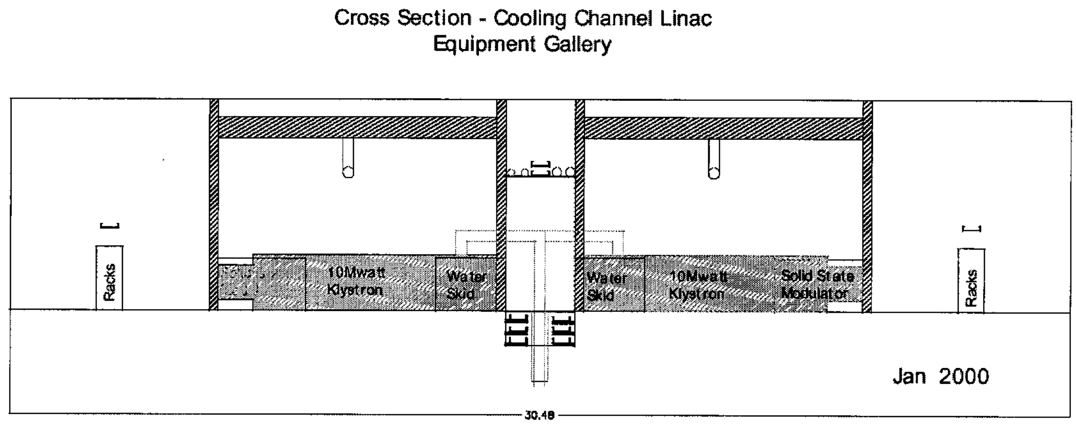


Figure 3: A surface building for the klystron gallery of the cooling channel would require substantial width and height. The width must accommodate the physical length of the low-frequency high-power klystrons and the height is needed for a crane for maintenance and exchange. A cross section is shown in the picture with klystrons on both sides to provide the required peak rf power per unit length to the cooling channel.

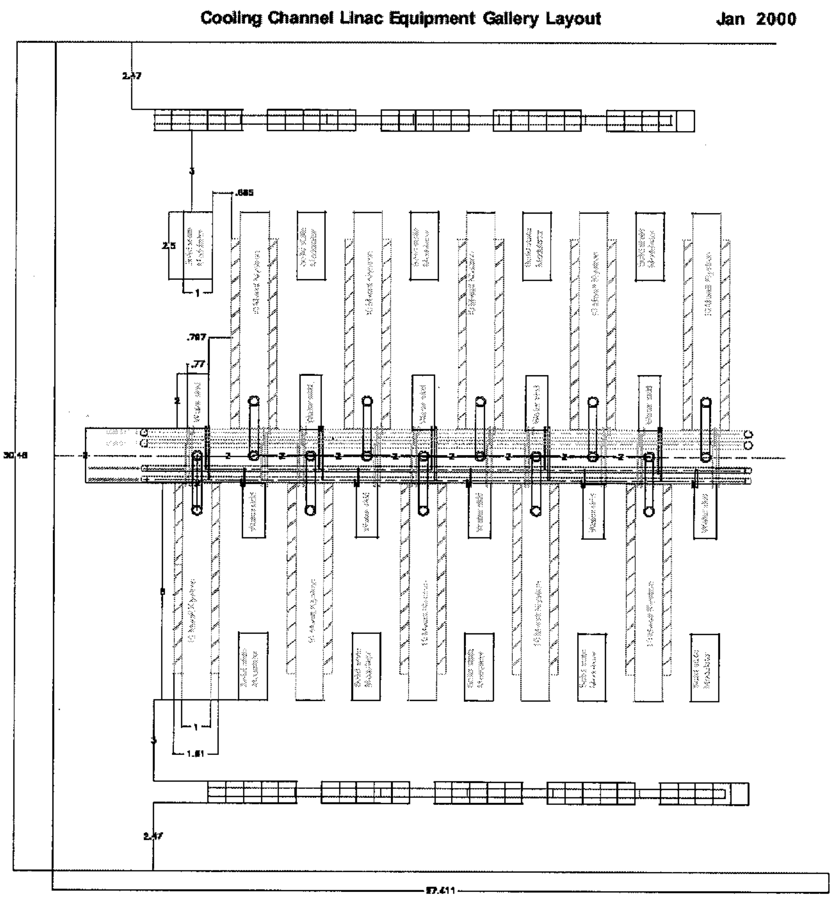


Figure 4: Top view of the klystron gallery. The gallery length is determined by the cooling channel length.

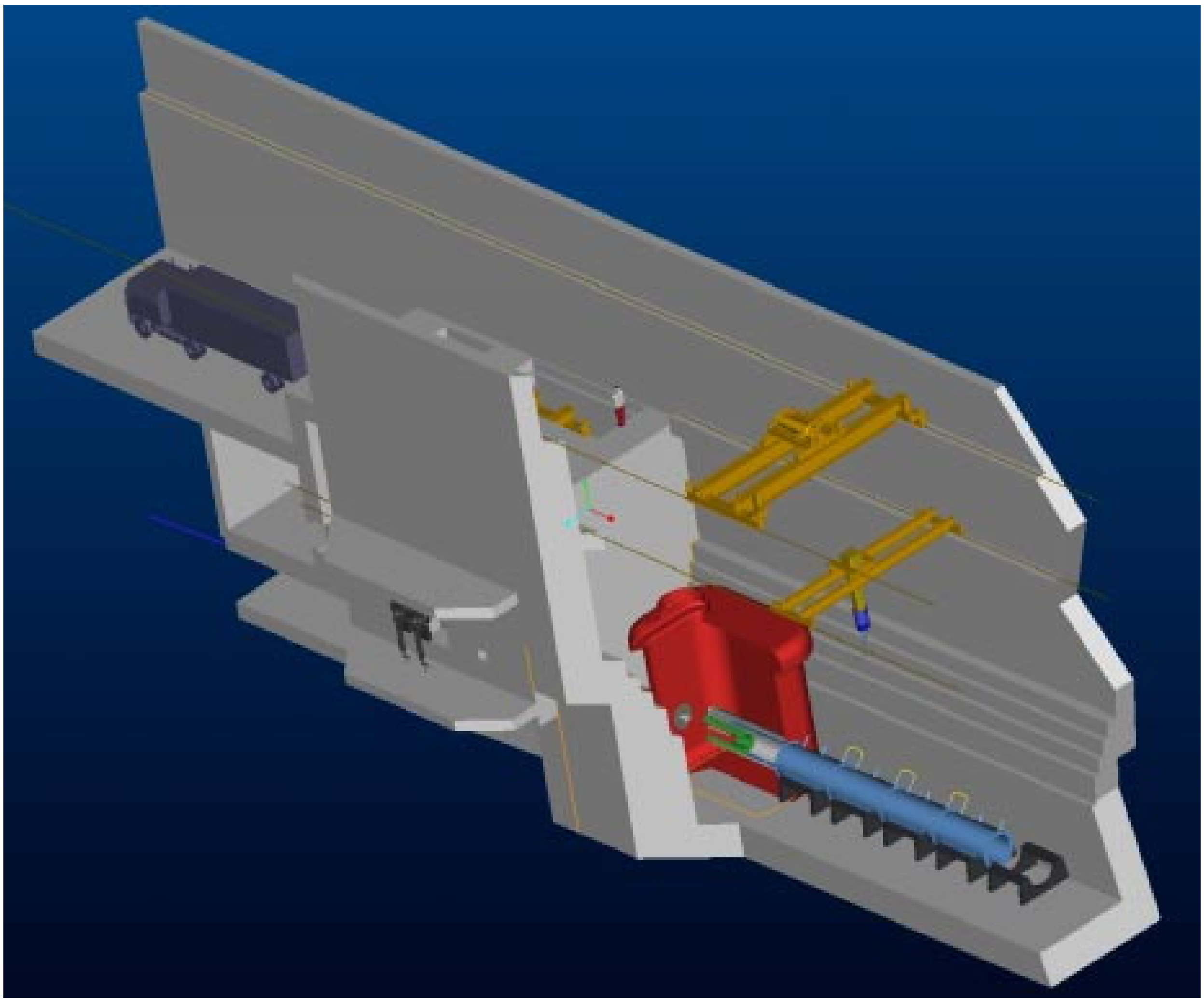
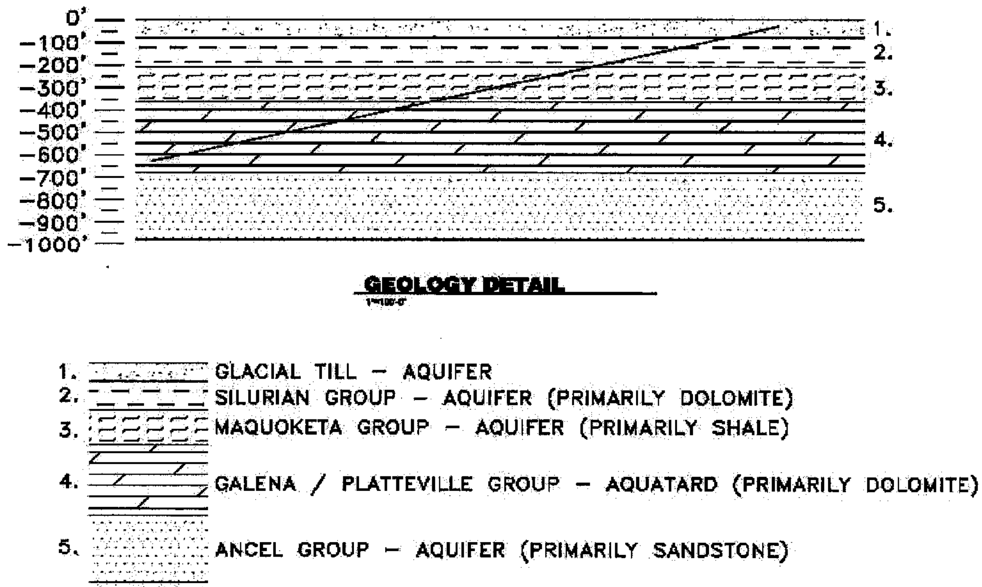
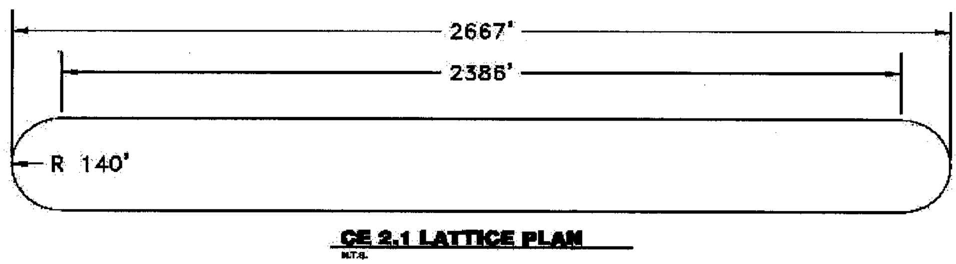


Figure 5: Sketch of the proton target hall for the Neutrino Source. Up to 4 MW average proton beam power is dumped into the target container (red container). The pions get captured and focused into a 1.25 T super-conducting solenoidal magnetic channel.



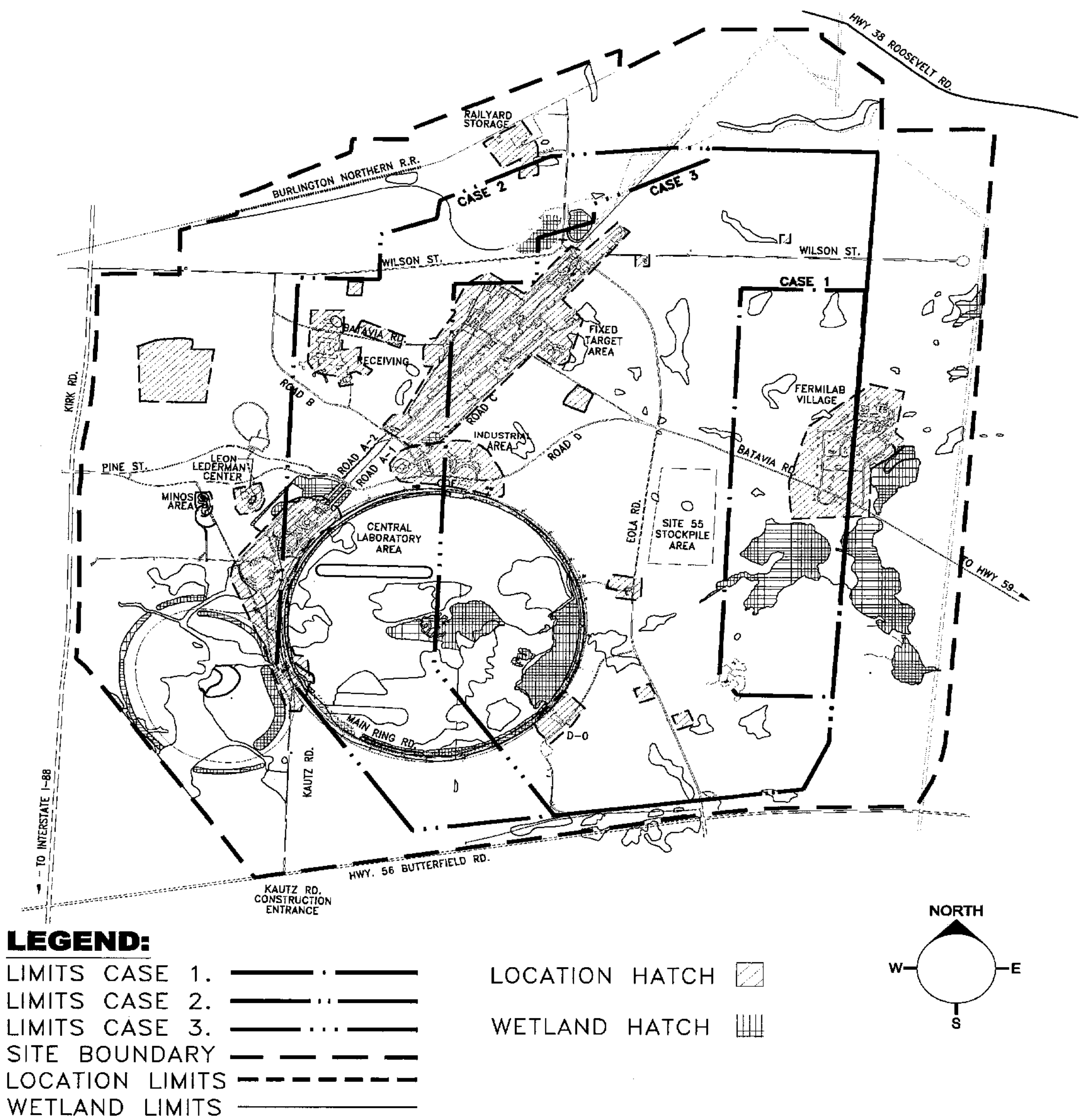


ORIENTATION:

NAME	AZIMUTH (DEG–MIN–SEC)	VERT. ANGLE (DEG–MIN–SEC)
PALO ALTO CA.	271–20'–42.27"	–13–09'–26.99"

MuSR
CTE 15-OCT-99

Figure 6: The figure above shows the geology beneath the Fermilab site. In addition the location of the storage ring is shown. It extends from the surface (minus shielding) down to the bottom of the Galena Platteville, approximately 250 meters under ground. The aquifer will not be penetrated because of the increased construction cost under such high water pressure.



LIMITS:	mrem/year	CONTROL CYL.	
CASE 1. 50GeV	10	4.5KM	RADIUS=4.0M
CASE 2. 50GeV	100	1.4KM	RADIUS=1.2M
CASE 3. 30GeV	10	2.5KM	RADIUS=5.0M

MuSR
CTE 15-OCT-99

Figure 7: Limiting boundary lines that correspond to specific limits for the maximum radiation dose accumulated per year. The west is set by the requirement not to exceed the federal limit outside the boundary, although at this point the neutrino beam is approximately 600 meters deep. The east boundary is somewhat arbitrary, and assumes a building is constructed off-site on the east side of Fermilab, with a height of ~200 meters. The neutrino beam hitting it would exceed the federal limit if the storage ring were built beyond the east boundary given by Case 2.

REFERENCES

[1] N. Holtkamp and D. Finley, editors, “Feasibility of a Neutrino Source Based on a Muon Storage Ring”, Fermilab pub-00/08-E, May 2000.

[2] status report.

[3] sg .

[4] C. Albright et al, (S. Geer and H. Schelman, editors), “Physics at a Neutrino Factory”, Fermilab-FN-692, May 2000.

6.3 Site Considerations for the Very Large Hadron Collider

Particle physics advances with experiments at the highest energy. The only sure way to advance to a higher-energy regime is through hadron colliders — the Tevatron, the LHC, and then, beyond that, a Very Large Hadron Collider. The recently completed "Design Study for a Very Large Hadron Collider" seeks to identify the best and cheapest way to arrive at frontier-energy physics, while simultaneously starting down a path that will eventually lead to the highest-energy collisions technologically possible in any accelerator using presently conceivable technology. The study describes a staged approach that offers exciting physics at each stage, and finally reaches an energy 100 times the highest energy currently achievable.

6.3.1 A Staged Approach to the VLHC

The staged approach to the VLHC starts with the construction and operation of a collider made from simple and inexpensive components, followed later by a higher-energy collider in the same tunnel. The plan has the following guidelines:

- Each stage must hold the promise of new and exciting particle physics.
- The first stage should lead to and assist in the realization of the next stage.
- Each stage should be a reasonably low-cost step into the energy frontier.

The VLHC satisfies these guidelines. The cost of tunneling is in general less than the cost of a collider's technical components. Thus, it is cost-effective to increase tunnel circumference if doing so lowers the cost of the expensive technical components enough to reduce the overall cost of the collider. Hence, Stage 1 of this design uses low-field superferric magnets that are themselves inexpensive, and that also require simple and less costly support systems. However, the use of a low-field magnet requires a large tunnel to reach the energy frontier. This design, used 40 TeV collision energy with two detectors, requiring a ring circumference of 233 km. The study has sited the collider at Fermilab, permitting the use of the existing Fermilab injector chain and physical plant, valued at well over $1 billion. It takes advantage of Fermilab's irreplaceable organizational infrastructure and expertise, further reducing design and startup costs.

6.3.2 The Technical Description and Challenges

Table 6.3.1 shows high-level parameters of both stages of the VLHC. At this early stage there appear to be few technical problems in reaching the listed performance of Stage 1. Making the arc magnets inexpensively and very long, as well as learning how to transport and install them in a tunnel, will take R&D investment over the next few years. It is particularly interesting to note the low average power consumption, comparable to that of Fermilab's 800 GeV fixed-target program. Power is mostly concentrated at the cryogenic service buildings, of which there are five off the existing Fermilab site. These double in number and grow larger for Stage 2.

Table 6.3.1. The high-level parameters of both stages of the VLHC.

	Stage 1	Stage 2
Total Circumference (km)	233	233
Center-of-Mass Energy (TeV)	40	175
Number of interaction regions	2	2
Peak luminosity ($cm^{-2}s^{-1}$)	1×10^{34}	2.0×10^{34}
Luminosity lifetime (hrs)	24	8
Injection energy (TeV)	0.9	10.0
Dipole field at collision energy (T)	2	9.8
Average arc bend radius (km)	35.0	35.0
Initial Number of Protons per Bunch	2.6×10^{10}	7.5×10^{9}
Bunch Spacing (ns)	18.8	18.8
β^* at collision (m)	0.3	0.71
Free space in the interaction region (m)	± 20	± 30
Inelastic cross section (mb)	100	130
Interactions per bunch crossing at L_{peak}	21	54
Synchrotron radiation power per meter (W/m/beam)	0.03	4.7
Average power use (MW) for collider ring	20	100
Total installed power (MW) for collider ring	30	250

The VLHC ring is tangent to the Tevatron, but much deeper. The injection lines bend very gradually, because they also serve as ramps to install the very long (65 m) Stage 1 magnets. The collider is deep in order to permit tunneling mostly in the extensive layer of excellent Galena-Platteville Dolomite. The collision halls are large and resemble those at LHC.

6.3.3 General Description

The staged approach to the VLHC requires placing two collider rings in a common tunnel, imposing constraints on the lattices of the rings as well as on the civil construction parameters. The injector to the collider is the existing Fermilab accelerator complex; hence the collider must pass through or close to Fermilab. The plan view of the 233 km VLHC collider is in Figure 6.3.1, which shows the service buildings (not to scale) that contain cryogenic refrigerators and other utilities. Stage 1 has six service areas (one on the Fermilab site) for cryogenics and other operational requirements. Stage 2 requires six additional service sites. The ring is almost circular, comprising two great arcs of 35 km average radius connected by two clusters, one at Fermilab, one exactly opposite, each six kilometers long and each containing straight sections and dispersion suppressor arcs. The straight sections are needed for injection, extraction, collisions and beam cleaning.

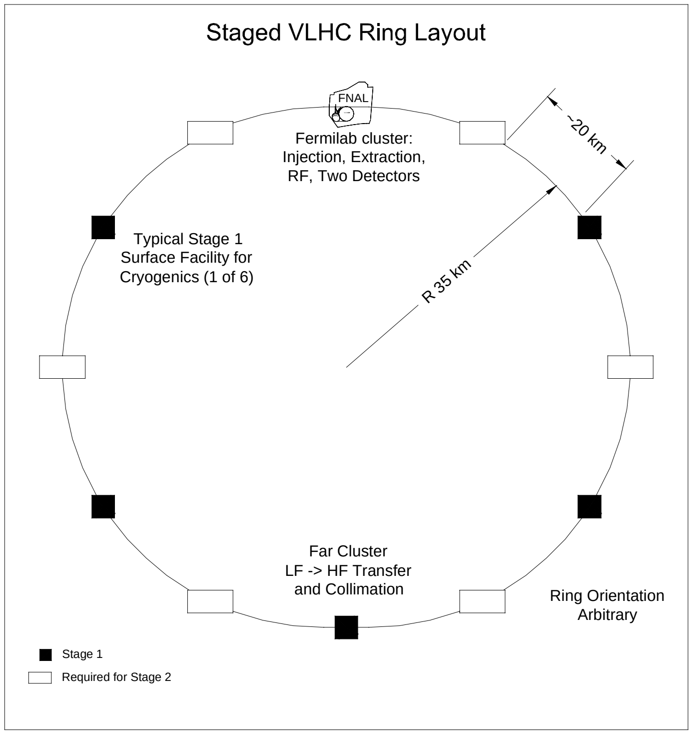


Figure 6.3.1. The 233 km VLHC ring.

A magnified view of the VLHC Fermilab cluster is shown in Figure 6.3.2 with one scale extremely expanded relative to the other. Grouped below or nearly below the existing Fermilab site are the underground injection and extraction beam lines, the beam absorber, and the RF acceleration stations. In the on-site straight sections are two detectors, far enough apart in distance and angle to prevent muon background from one detector from hitting the other. The cluster opposite the Fermilab site is mostly passive, although a second campus could be developed there. The machine functions at the far cluster are beam scraping and, eventually, the systems for beam transfer from Stage 1 to Stage 2. Several different injection layouts from the Tevatron are possible. To take advantage of the best geology in the area, the VLHC tunnel is approximately 120 m below the surface at Fermilab, much deeper than the Tevatron, but about the same as the LHC.

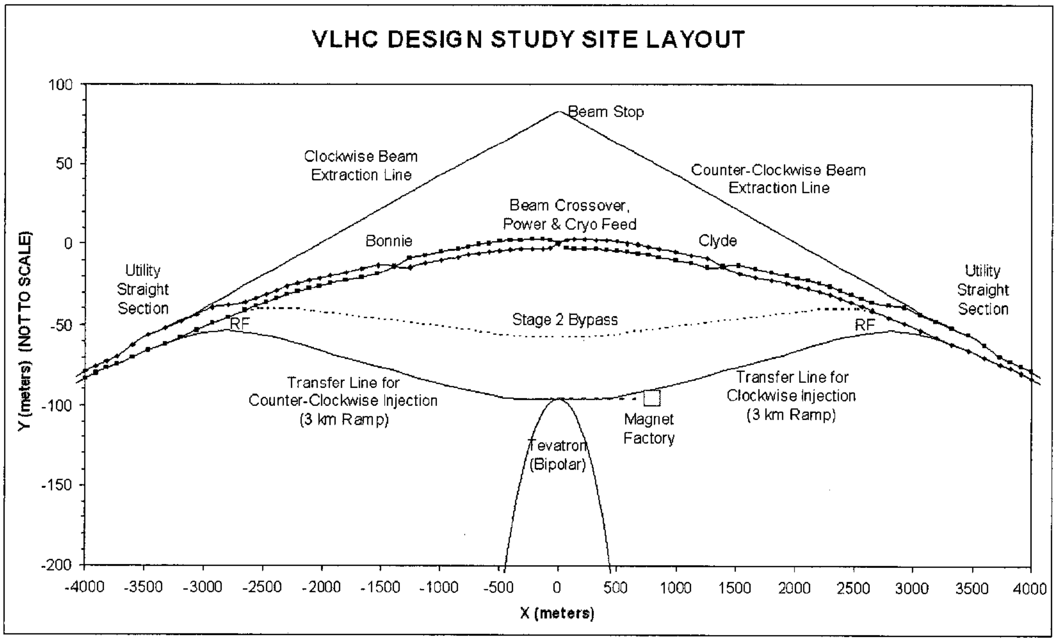


Figure 6.3.2 VLHC cluster at Fermilab, showing the various functions. Note the differences in E-W and N-S scales.

The lengths of the injection lines are determined by the need to descend gradually to that depth so that these ramps can be used during the construction phase for the installation of magnets and other technical components. A similar ramp is used for installation on the far side of the VLHC ring.

The tunnel for the Design Study is a standard tunnel, similar in size to the SSC and LHC tunnels, and made by standard construction techniques. A cross section view of the tunnel at its minimum finished diameter of 12 feet and minimum floor width of 10 feet is shown in Figure 6.3.3, with both Stage 1 and 2 colliders installed. Notable are the small Stage 1 combined-function magnet installed on stands on the floor of the tunnel, and the small amount of necessary infrastructure. For example, there are only two small cable trays, because all of the correction elements are powered from local supplies installed in wall penetrations, and all of the instrumentation and controls are local, with only fast communication to the rest of the world. An electric trolley line provides power for tunnel transportation and local work power. This design eliminates almost all long cables except for ring-wide power cables and some bundles of optical fiber.

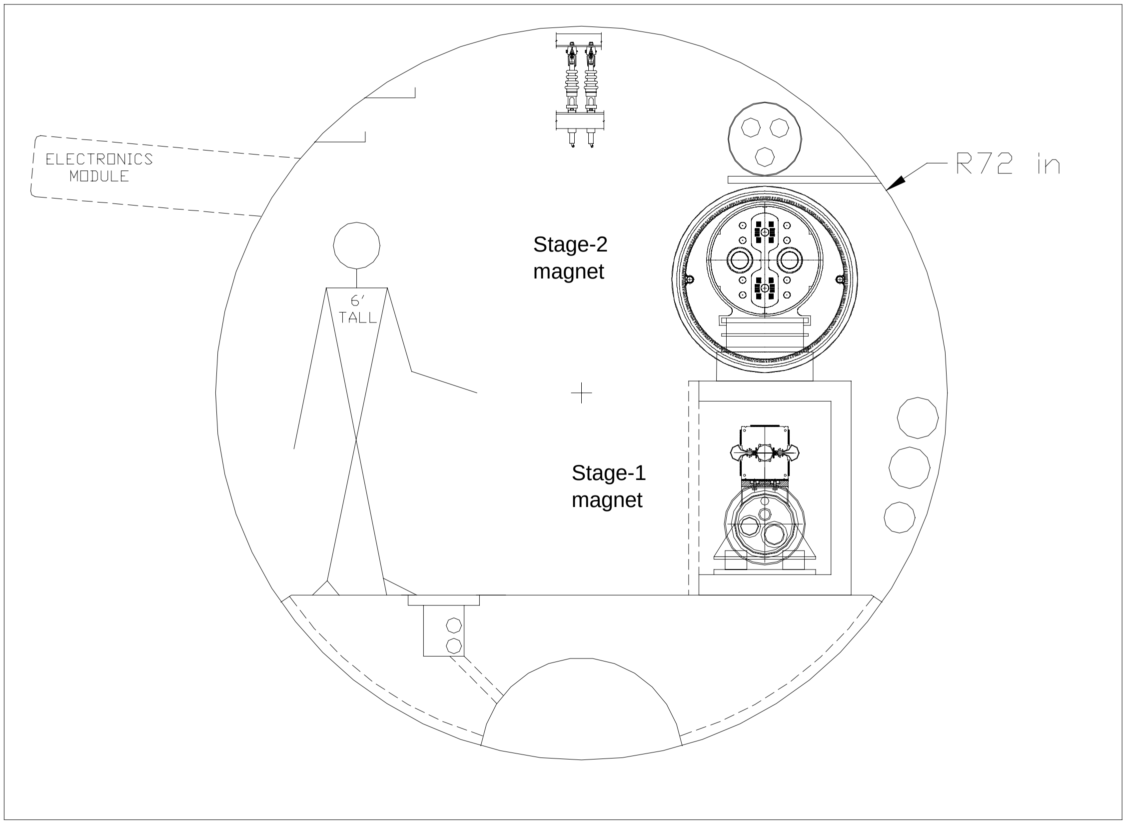


Figure 6.3.3. A cross section of the VLHC tunnel with both the Stage-1 and the Stage-2 magnets in place

Sections of the tunnel used for services will have to be larger than the nominal minimum of 12 feet. The long straight sections for injection and extraction and experimental areas, the tunnel below the major service buildings, and anywhere where two tunnels join will be among them. In addition, there is an adit to the tunnel every 10 km that contains cryogenic valve boxes and transformers and bulk power supplies for DC power distribution in the tunnel. There are additional personnel exits every 5 km between the 10 km points. Tunnel locations under the service areas and the future locations of the Stage 2 service areas will have adits sized for Stage 2 during the initial construction.

6.3.4 Geology of the Fermilab Region as Applied to VLHC

The terrain in northern Illinois is excellent for building large accelerators. The surface is flat, and there are thick layers of self-supporting and competent rock underground. The geology is not perfect, however. The best rock for tunneling, the Galena-Platteville dolomite, is deep underground and is tilted down to the east. There is an inactive fault west and south of Fermilab with a large mismatch of geological properties on either side and a disturbance from a large meteor strike near Des Plaines. Due to its greater circumference (233 km), a VLHC might extend beyond the region where it is practical, or possible, to site the tunnel entirely in the Galena-Platteville. An earlier geological study for various VLHC configurations was reported by Conroy [5]. There has been substantial experience in the Chicago area [6,7] in tunneling and underground caverns in the Silurian dolomite, Maquoketa shale, and Galena-Platteville dolomite. There is a lack of corresponding local similar experience, or even knowledge of the mechanical/structural engineering properties of the underlying units consisting of the Ancell, Middle Confining unit, and the Franconia formation. In order to sample all of the features in the area, and to get an idea of the technical, environmental and cost issues involved in tunneling through various media, we have included three tunnel orientations.

- A south ring with a 0.08% incline and a depth at Fermilab of 235 feet. This orientation requires tunneling through the Sandwich fault and is relatively shallow.
- A north ring, with no incline and a depth at Fermilab of 330 feet. This orientation samples numerous types of underground media.
- A north ring with a 0.20% incline and depth at Fermilab of 500 feet. This ring is inclined to stay exclusively in the Galena-Platteville dolomite. It is very deep in some locations.

By studying the three different orientations, we hope to learn the unit costs (per mile, per shaft, lined/unlined, etc.) of a tunnel in an excellent medium, that of a tunnel transitioning among three different rock media, and that of a tunnel which combines rock media, traversing the Sandwich Fault, and the sandstone and dolomitic sandstones, both within the aquifer, and beyond. These data will allow optimizations and tradeoffs with respect to siting costs.

The tunnel in the dolomite will not be lined but may have to be grouted and sealed in places. Some of the tunnel will have to be lined in order support poorer quality material and to avoid excessive inflow of water, which we have specified as no more than an average of 50 gallons per minute per mile of tunnel. Large underground cisterns are constructed as part of the tunnel near the six major service areas, and pumps with emergency backup empty them, creating a potential environmental issue.

There is a general sloping of the till, Silurian, Maquoketa, Galena-Platteville, Ancell sequence of layers from the west (higher elevation above mean sea level) to the east (lower elevation) to Lake Michigan. However, to the northwest and west of Fermilab are located the Troy and Rock Bedrock Valleys, where the Silurian, Maquoketa, and Galena-Platteville layers have been completely cut away by glaciers and filled to the underlying sandstones with glacial drift. The Sandwich Fault Zone lies to the southwest of Fermilab, passing through Sandwich, Illinois, and running roughly NW to SE. This fault zone ends approximately SSE of Fermilab. To the southwest of the Sandwich Fault Zone, the underlying Ancell and Middle Confining layers are upthrust to meet the glacial drift at the bedrock surface, and even the Franconia layer can affect tunnels traversing the fault zone.

The Des Plaines disturbance, as shown in Figure 6.3.4, is an unusual structure, possibly an ancient meteor impact. The rocks in the disturbance, in an area about 5 ½ miles in diameter, are reported to be intensely faulted. This disturbance was encountered during construction of the TARP tunnels, but did not cause any significant problems.

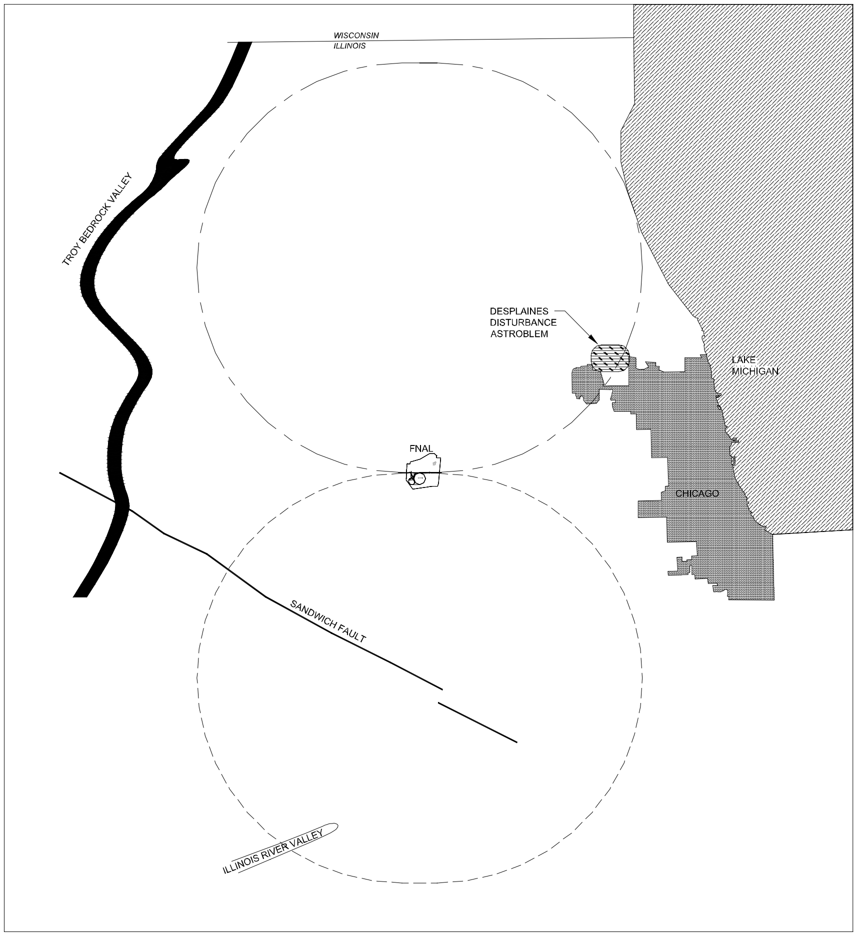


Figure 6.3.4. General geologic features of Northeastern Illinois with one southern and two northern ring orientations under study. One of the northern orientations is flat, the other tilted to stay entirely within the Galena-Platteveille dolomite.

The study region is in an area of the central mid-continent that is tectonically stable with a very low seismic hazard. Active faults are not known in the study area, and the last movement on the Sandwich Fault Zone has been demonstrated to be more than 200,000 years ago. The closest known earthquake source zones capable of producing ground motions of any significance to engineering design or operational requirements are located several hundred miles to the south.

If we restrict consideration to rings that would be contiguous to the existing Tevatron, only a VLHC ring with its center oriented to the north of Fermilab (North Ring) could be completely contained within the Galena-Platteville dolomite. This ring would have a roughly north-south strike axis passing through Fermilab with a tilt of approximately 0.2 % grade to stay within the dolomite. Lake Michigan and the Wisconsin border would bound this ring. Any ring with its center oriented farther to the west (even NNW) would be affected by the bedrock valleys. Possible rings oriented to the south or west would traverse the Sandwich fault into the strata underlying the Galena-Platteville.

In order to undertake a tunnel costing and feasibility study for various orientations of a VLHC ring, two layouts and vertical strata lampshades were prepared [8]. The simplest configuration is a tilted (0.2% incline) North Ring, which stays completely in Galena-Platteville dolomite. The second is a horizontal North Ring which transitions between the following media: Maquoketa shale, Silurian dolomite, Maquoketa shale, Galena-Platteville dolomite, and back into Maquoketa shale. The third is a tilted South Ring, which crosses the Sandwich Fault (only once) into the sandstone Ancell aquifer (wet) and the dolomitic sandstone Middle Confining unit and possibly the Franconia formation. These rings are shown in plan in Figure 6.3.4, and the two north-oriented rings are shown in section in Figure 6.3.5. Elevation parameters and the percentage of tunneling medium for each of these rings are listed in Table 6.3.2.

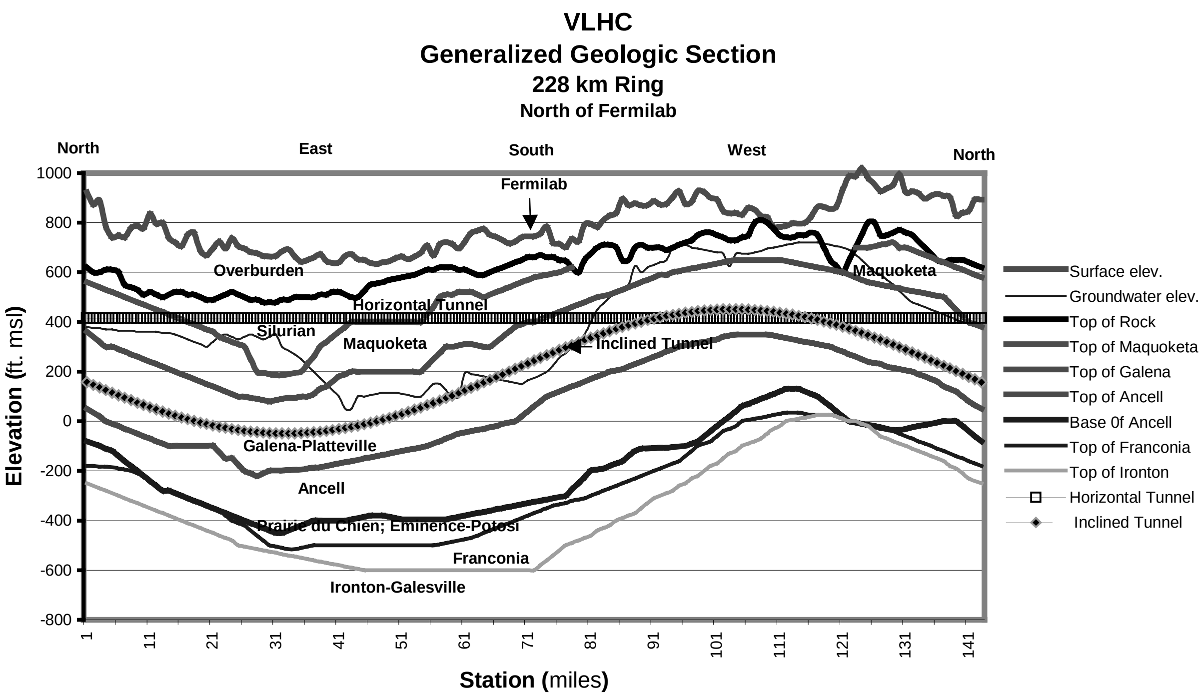


Figure 6.3.5. Lampshade diagram for North Ring orientation for horizontal and inclined tunnels.

Table 6.3.2. Elevation Parameters and strata fraction for three tunnel models:

	South Ring 0.08 % incline	**North Ring horizontal**	**North Ring 0.2 % incline**
elevation at Fermilab (ft msl)	510	415	244
depth at Fermilab (feet)	235	330	501
average depth (feet)	277	371	585
r.m.s. depth (feet)	61	99	121
minimum depth (feet)	118	219	342
maximum depth (feet)	406	603	779
Strata (approximate %)			
Silurian dolomite	29 %	27 %	
Maquoketa shale	34 %	27 %	
Galena-Platteville dolomite	21 %	46 %	100 %
Ancell – St. Peter sandstone	6 %		
Middle Confining layer: Prairie du Chien, Eminence-Postosi dolomitic sandstones	10 %		

6.3.5 Injection line tunnels (various scenarios), beam abort lines, equipment access ramps, and Stage 2 low-field ring bypass

There are various options for injecting from the Tevatron into the VLHC. For any option chosen, the Tevatron tunnel will have new line(s) tangential to it. These lines will pitch downward to the VLHC elevation as shown in Figure 6.3.7. The major slope of this injection tunnel could be up to 4.2 % grade, flat enough to serve as part of the equipment access ramps. There will be an incentive to cross the boundary between glacial drift and bedrock surface as steeply as possible to reduce both complexity of construction and ground water influx at the interface. The beam injection tunnels will also serve as the equipment access ramps, branching off from the injection tunnels and continuing to the surface. It will be important to design and schedule the construction of this geometry to allow VLHC component installation during beam operations of the Tevatron.

There also will be two sets of straight tunnels connected to the two near-Fermilab Utility Straight Sections, one set for the injection lines from the Tevatron to the Stage 1 low-field ring and equipment access ramps to the surface, the other for the abort beam lines of both the Stage 1 and Stage 2 high-field ring. Table 6.3.3 includes the length of arcs for unipolar single beam and unipolar two-extracted-beams configurations. Some of the lines for injection, abort and equipment ramps could likely share some common tunnel sections. However, the lines are now listed independently. The interfaces between these tunnels have not yet been designed. It will be important to configure the equipment ramps to allow access to the VLHC tunnel while the Tevatron program is in operation.

It is planned to operate the Stage-1 VLHC with the low-field, superferric magnet ring. For Stage 2, a high-field superconducting ring will be added. The low-field ring will serve as injector to the high-field ring. The beam transfer from low-field ring to high-field ring would occur in the straight sections opposite Fermilab. In order to remove the second, non-colliding beam and reduce crowding in the experimental areas and also allow access to the experimental halls/caverns while the low-field ring is performing accelerator studies, a small section (approximately 7 km) of the low-field ring will move to a bypass tunnel. In Stage 2 additional and stronger bends will be added to the low-field ring in this region to match its beam arc length to that of the high-field ring through the main tunnel. The current model provides stubs at the 28.4-mrad bend enclosures to allow later construction of this bypass tunnel for the low-field ring in Stage 2. No such bypass is planned for the far-side cluster of straight sections. All of these special tunnel sections would have the same inner finished diameter as that of the main tunnel.

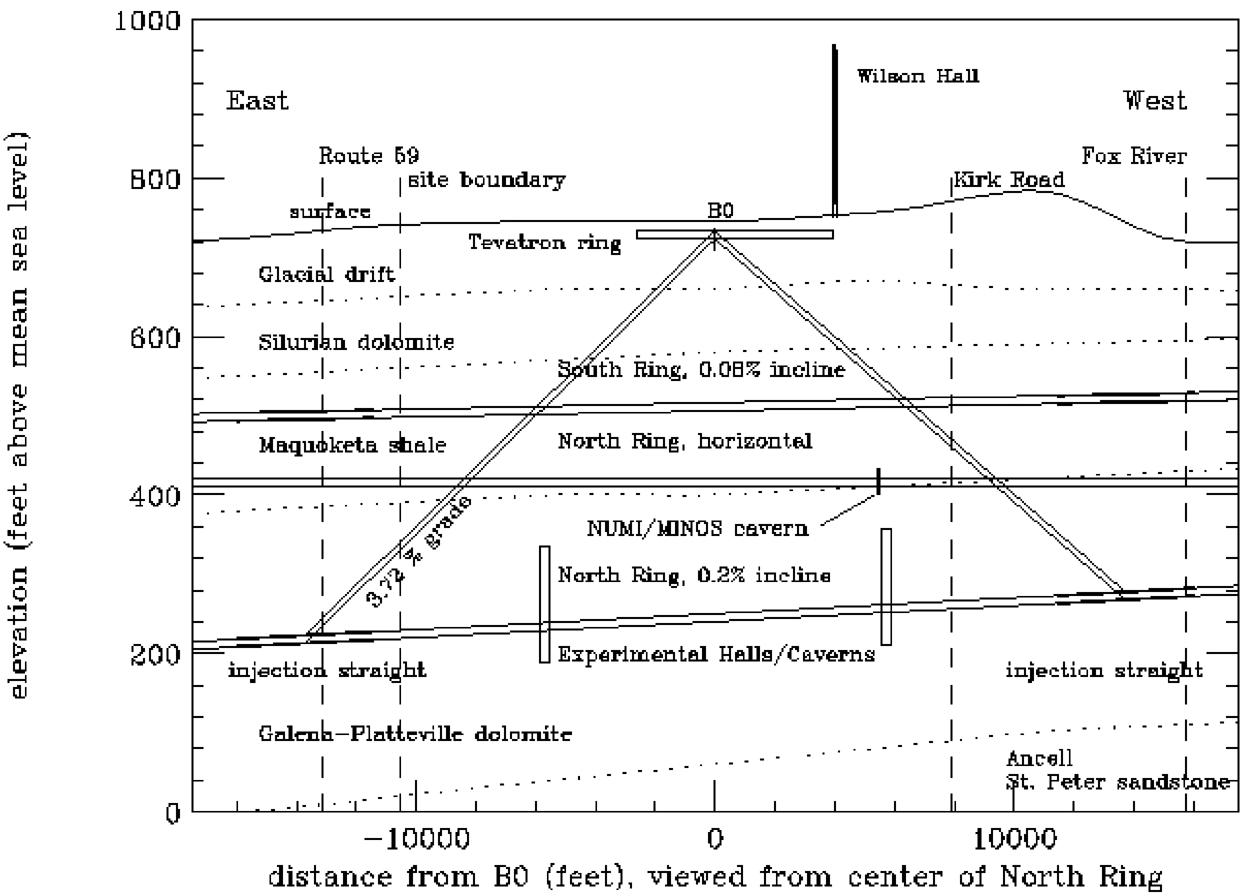


Figure 6.3.7. Schematic of injection ramps for inclined North Ring configuration.

Table 6.3.3. Special Tunnel Sections (same finished diameter as main tunnel).

Function	#	Length ea.	Comments - all located at Fermilab site
Access Ramps	2	< 1 km	Branch from Injection Lines near surface, up to 4 % grade to surface (745 ft msl) (possibly 1 access on side opposite Fermilab)
Abort Lines	2	3.7 km	at tunnel level to common abort/beam stop cavern
Injection Lines	2	Varies: 3.5 km or 5.7 km or 3.7 km	Tevatron (722 ft msl) to VLHC Utility Straight Section (bipolar configuration) (unipolar with 3.5 km radius of curvature) (unipolar with two extracted beams configuration)
Exp. Hall Bypass	2	0.55 km	radius = 2.0 km, offset = 25 meters
LF Ring Bypass	1	7.0 km	Stage 2 construction only, radius = 2.0 km

6.3.6 Surface Features

The most prominent off-site surface features of the VLHC will be the service buildings for refrigeration and other utilities for the collider. Stage 1 needs only six service buildings, roughly 40 km apart. A typical Stage 1 service area is shown in Figure 6.3.8. One of these is on the Fermilab site and is larger than the others to accommodate additional utilities and heat load required by the experimental areas.

The six Stage-1 service areas are modest, each requiring up to ~10 acres of space, including heat rejection systems and 5 MW of installed power. Stage 2 will require six additional sites approximately halfway between the Stage-1 service areas. In this upgrade, all 12 sites will require 40 acres each, as shown in Figure 6.3.9, with approximately 20 MW of installed power per site. The land use requirements depend on the mix of cooling ponds versus cooling towers chosen for each service area. Land availability and aesthetics are as important as the technical cost issues in these choices. The heat rejection capability for Stage 2 compressors is about 8 MW per service area. Minor areas are present at approximately five-kilometer intervals. They will have small buildings to cover and interlock the personnel exits and contain backup (generator) power for the elevators and lights. Every 10 km these buildings will be slightly larger because of additional underground utilities and power requirements.

The two detector caverns and associated service buildings are on the Fermilab site. These caverns are sized according to the SSC design and are 100 m by 30 m by 45 m high. It will be convenient but not necessarily possible to construct them deep enough so that their roofs have a thick enough dolomite cover that they will be self-supporting over that large span. The two areas have bending between them so that the background muons generated in one interaction region will not appear in the other. Experiments similar to those being built for LHC are thought to be adequate for the 40 TeV collisions of the Stage 1 VLHC. Adjacent to the two access ramps at the Fermilab site (and possibly at an additional access ramp opposite), there will be the need for a warehouse, assembly, cryo testing, and storage building for final fabrication of the long magnet and cryogenics systems to be installed in the tunnel.

This building will measure 690 ft. x 460 ft. with a variety of cranes and lifting devices with capacities up to 50 tons. The size, capacity and complexity of the cryogenics test station/facility associated with these factories for Stage 1 components will be similar to that of the Fermilab Magnet Test Facility (MTF).

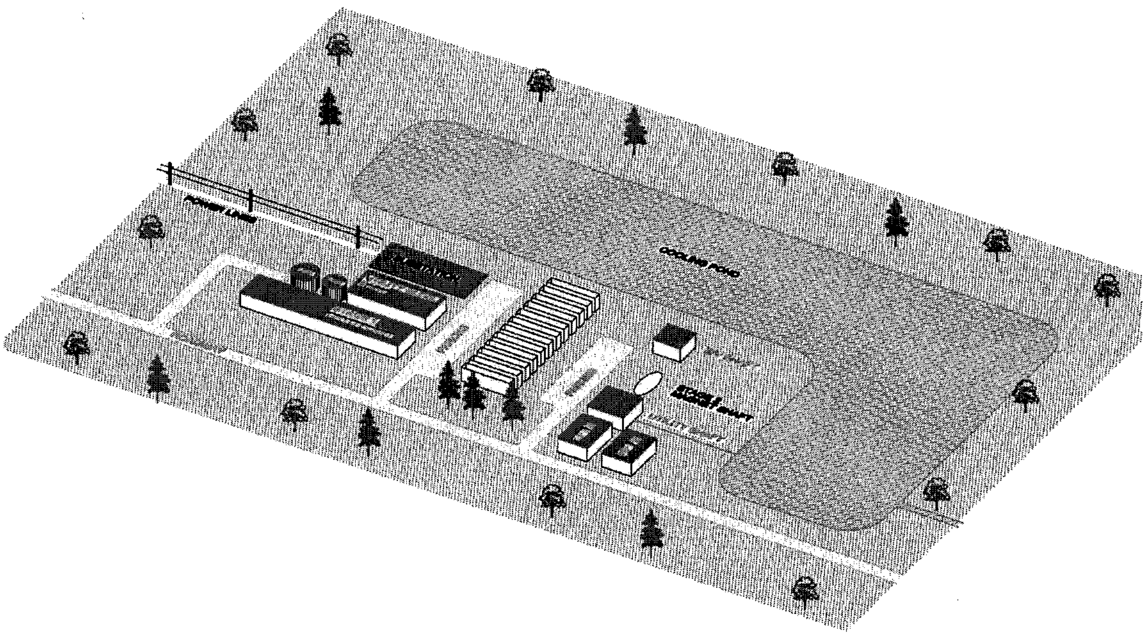


Fig. 6.3.8 Plan view of a 40-acre service area for Stage 2.

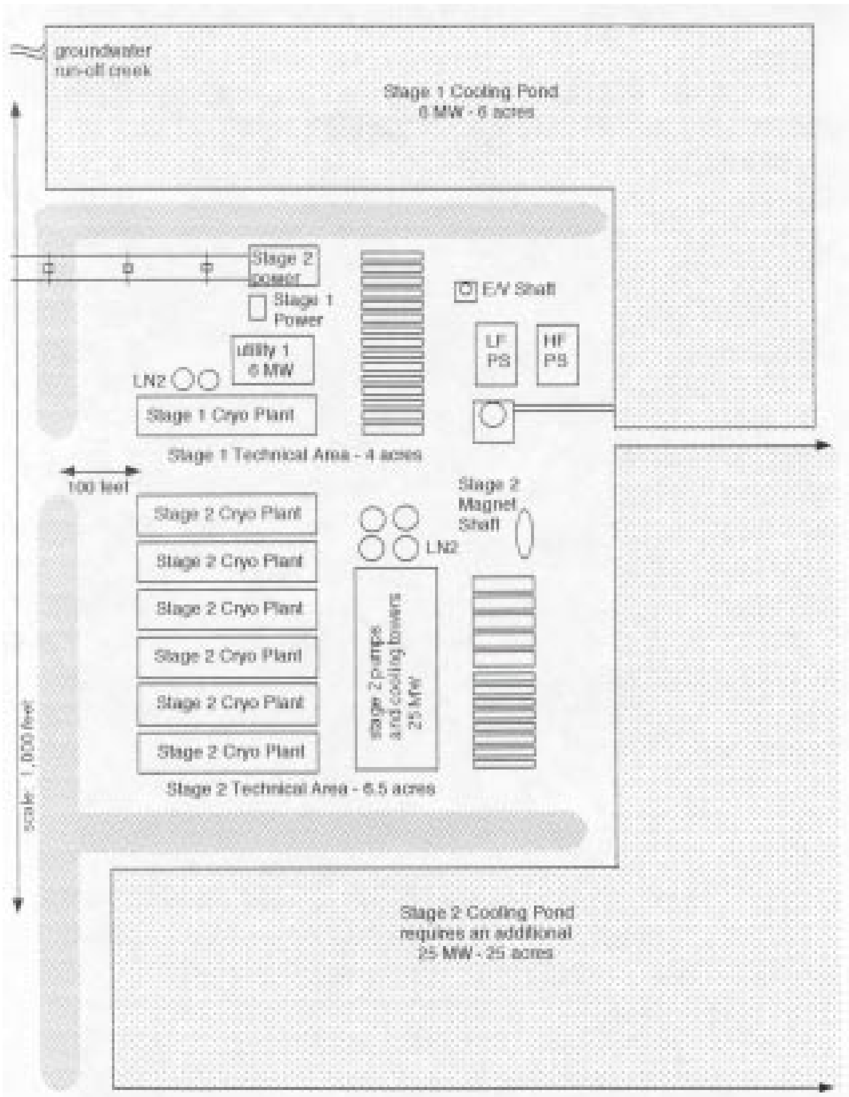


Figure 6.3.9. Cryogenics and Utility Plants at A-sites for Stage 1 and Stage 2

6.3.7 Experimental Caverns

The design provides for two experimental caverns and installations in the IR straight sections at the Fermilab site. These caverns, major access shafts and associated surface structures for experimental apparatus fabrication, staging and operations, will be located on the Fermilab site. The model chosen is that of the designs of the caverns for the GEM and SDC experiments at the SSC [11,12]. The current model assumes only one pair of experiment caverns, placed along the tunnel of the Stage 2 ring. For Stage 2, the low-field ring will be displaced through its low-field ring bypass tunnel, away from the experimental caverns. There will be no interaction regions or experimental caverns in the Stage 2 low field bypass. For Stage 2, the experiments will have to upgrade to the four times higher energy. The upgrade will include a vertical change in the position of the interaction point, due to the difference in elevations of the low-field and high-field rings.

The experimental caverns are envisioned to be 30 m × 45 m × 100 m (W × H × L) similar to the SSC model depicted in Figure 6.3.10. Structural features and thickness of the strata supporting the spans of the experimental halls or caverns [2] will determine the elevations of caverns. This, of course, determines the elevation of the collider tunnel at the site of the cavern. A general rule is that there should be a depth of rock (dolomite) strata above the cavern at least equal to the span of the cavern. A previous study has concluded that for 75-foot high chambers, roof spans up to 125 feet are feasible using standard methods of roof arching and rock supports. This study assumed that the orientation axis of the cavern bisects the major joint sets.

Another design constraint deals with the positioning and depth of the caverns for the two experimental halls. It is desirable to have these located at the Fermilab site to be able to cluster the long straight sections (for injection/abort and interaction regions) and to use the Fermilab campus for the related experiment fabrication and staging buildings, support utilities, and equipment shaft facilities, and to minimize off-site surface land requirements.
This, of course, impacts the elevation of the accelerator tunnel at the site of the cavern. A general rule of thumb is that there should be a depth of rock (dolomite) strata above the cavern at least equal to the span of the cavern. Previous studies [1,2] have concluded that for 75-foot high chambers, roof spans up to 125 feet are feasible using standard methods of roof arching and rock supports. This assumed that the orientation axis of the cavern bisects the major joint sets. The joints run approximately NE-SW × NW-SE so these criteria would be satisfied by VLHC ring orientations to the North, South, or West. Possible options in elevation for the experimental caverns are depicted in Figure 6.3.6.

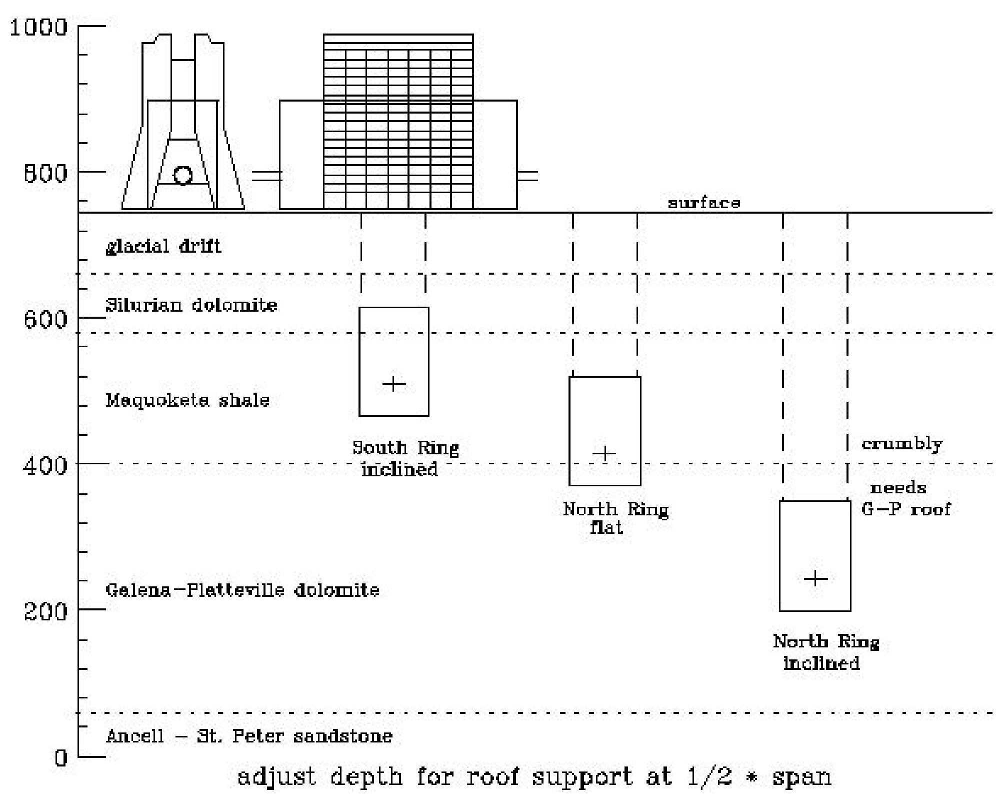


Figure 6.3.10. Vertical siting of the experimental halls/caverns (and therefore VLHC).

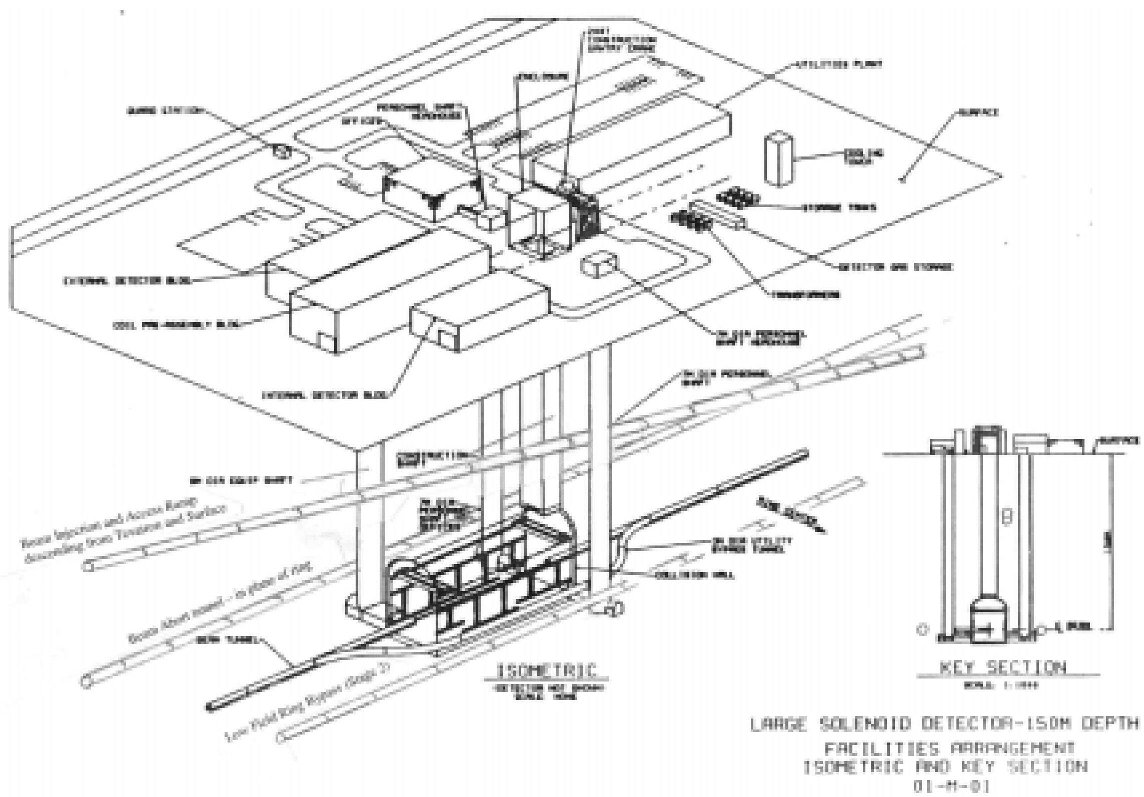


Figure 6.3.10. Experimental Area, isometric, modeled on SSC generic Large Solenoid Detector.

The design includes a tunnel bypass, to allow free access and transport of accelerator personnel, utilities, and equipment without entering the experimental caverns. A 25-meter maximum offset can be accommodated with 2 km radius bends over a total bypass length of 550 meters (including the 100 meter length of the experimental halls). This would be of the same diameter as the main tunnel. Likewise, the tunnels for the abort line and the sloped tunnels for the injection lines/access ramps will pass near the experimental halls.

CHAPTER 7. SUMMARY AND CONCLUSIONS

Fermilab is the flagship laboratory of the U.S. high-energy physics program. The Fermilab accelerator complex has occupied the energy frontier nearly continuously since its construction in the early 1970s. It will remain at the frontier until the Large Hadron Collider at CERN begins operating in 2006-7. A healthy future for Fermilab will likely require construction of a new accelerator in the post-LHC era. The process of identifying, constructing and operating a future forefront facility will require the support of the world high-energy-physics community, the governments and funding agencies of many nations and the people of surrounding communities.

This report explores options for construction of a new facility on or near the existing Fermilab site. We began the study that forms the basis of this report with the idea that Fermilab, and the surrounding area of northeastern Illinois, possesses attributes that make it an attractive candidate for a new accelerator construction project: excellent geology; a Fermilab staff and local contractors who are experienced in subsurface construction; abundant energy supplies; good access to transportation networks; the presence of local universities with strong interest and participation in the Fermilab research program; Fermilab's demonstrated ability to mount large accelerator construction projects and operate complex accelerator facilities; and a surrounding community that is largely supportive of Fermilab's presence. Our report largely confirms these perceptions.

Three sorts of facilities are identified as candidates for a future forefront facility on or near the Fermilab site:

- A muon-storage-ring-based "neutrino factory"
- An electron-positron linear collider
- A very large hadron collider

The single most important feature of these facilities, from the point of view of this report, is physical size. Sizes range from about 2 km by 300 m for the neutrino factory, to 30 km by 100 m for a linear collider, to 100-300 km by 100 m for a very large hadron collider. Any of these facilities would be located underground and would require surface support buildings. Only the neutrino factory could be situated entirely on the existing Fermilab site. In general, complicating factors increase with size—the number of different geological conditions encountered; the need to supply utilities from multiple (as opposed to single) sources; the potential impact on the surrounding communities; and the logistics involved in construction, operation and maintenance of the facility.

Geology and Tunneling

Northeastern Illinois has a geology that is conducive to tunneling. The Tunnel and Reservoir Plan (TARP) Project in the Chicago area has constructed over 100 miles of tunnel over the past few decades. These tunnels (and reservoirs), used for storm water management, lie largely in the Galena-Platteville dolomite layer that extends from 100 to 150 m below the surface of the Chicago area. Extensive experience with construction in this layer provides the basis of the conclusion of this report that Fermilab sits on top of a very favorable geology for the site of a future large accelerator facility. The linear collider could be situated entirely within this stratum, with the possible exception of beamline and access connections to surface facilities. The muon storage ring would traverse this and all overlying strata. The very large hadron collider, at least with the circumference described in this report, would be difficult to site entirely in the Galena-Platteville because of non-uniformities in the subsurface geology over the extent of the accelerator. As described in the report this presents construction complications, but none appear insurmountable.

We also discuss a near-surface linear collider. Such a site would lie in the glacial deposits above the underlying bedrock, facilitating access and maintenance. However, a near-surface site would also entail a greater surface presence that would likely preclude construction in any urban or suburban area. Ground motion could also become more of an issue in a near-surface tunnel.

At present, it is unclear whether a near-surface or deep-tunnel configuration would serve better. However, Fermilab's extensive experience in the design and construction of near-surface enclosures, combined with the experience of the ongoing NuMI tunneling project, provides valuable institutional understanding of the type of work required to build a linear collider, neutrino factory, or very large hadron collider.

Utilities Infrastructure

Factors considered in this report include electrical power, natural gas and cooling capacity. The facilities under consideration would draw between 100 to 300 MW of power. The total existing Fermilab site capacity is about 320 MW, with site demand currently in the 30 to 50 MW range. Thus existing infrastructure on the Fermilab site would likely support the neutrino factory or a linear collider that derived its power from the Fermilab site. The ability of the local power utility, Commonwealth Edison, to deliver excess power from existing transmission lines serving the laboratory is estimated to lie somewhere between 20 and 100 MW. Current local utility capacity may be sufficient or may require augmentation in support of a linear collider or a neutrino factory, depending on how much the laboratory curtails operations of the current accelerator complex after beginning operation of a new facility; and on the evolution of demand and production and distribution capacity within the ComEd service area.

The construction of a linear collider to the west of the Fermilab site would require the creation of a completely new set of substations and power distribution systems. We have assumed that such a facility would still rely on a centralized utility distribution system. Whether this would require new ComEd distribution lines is unknown and would depend upon details of the electrical power requirements, the specific facility location, and overall configuration of and demands on the ComEd distribution system.

Because of its physical extent, a very large hadron collider would rely on a distributed configuration of utilities. It does not seem practical to imagine distribution of power from a central location over a several-hundred-kilometer facility. Rather, we have imagined that power would be picked up from local distribution systems at major surface service buildings.

The above conclusions about power distribution apply also to the other utilities investigated in this report—natural gas and cooling. It is fair to say that from the point of view of utilities support, a facility on or traversing the existing Fermilab site is preferred, but that infrastructure either exists or could be created in northeastern Illinois to support an off-site facility.

Environment, Safety, and Health

Issues related to protection of the environment, and to the safety and health of the public and workers, in any of the facilities examined are for the most part well known at Fermilab and in other accelerator laboratories around the world. Both the construction and operations phases need to be considered. Construction-phase issues are largely confined to environmental protection and occupational safety, while control of ionizing radiation is added once operations start. The planning for and construction of any project of the scope described in this report will be subject to many, many regulatory requirements derived from the National Environmental Policy Act (NEPA) and promulgated by the U.S. Department of Energy, the U.S. Environmental Protection Agency, the U.S. Army Corps of Engineers, and the Illinois Environmental Protection Agency. In addition the Occupational Health and Safety Administration (OSHA) regulates worker safety during both construction and operation. Permits will be required to cover such areas as wetlands impacts, construction in floodplains, storm water and cooling water discharges, control of air pollutants (both non-radioactive and radioactive), erosion controls, tunnel dewatering, and fire and life-safety protection. It appears likely that an Environmental Impact Statement (EIS) would be required for any facility that extends off the existing site. An EIS might also be required of a neutrino factory, although for the construction and operation of new facilities on the Fermilab site the laboratory has found that Environmental Assessments concluding in Findings of No Significant Impact (FONSIs) issued by DOE have adequately addressed the requirements of NEPA.

While Fermilab has many years of experience with the kinds of issues that will need to be addressed in the planning and execution of a new forefront facility on or near the Fermilab site, the scope of any of these facilities would lead to novel and unusual features. They would include life-safety issues in a tunnel tens to hundreds of kilometers in length or circumference and a few hundred meters below the surface, the safe disposition of beams containing Gigajoules of stored energy or Megawatts of power, and the unusual features of neutrino beams leaving the surface of the earth in the case of the neutrino factory. However, these issues do not appear to be intractable as long as they are recognized and adequately accommodated in the design phase of a new facility.

Public Acceptance

Fermilab will need support from the surrounding communities before embarking upon the construction of a new forefront facility on or near the Fermilab site. While the communities surrounding Fermilab are generally supportive of the laboratory and consider Fermilab to be a good neighbor, inevitable concerns will arise regarding any future facility. Fermilab will need to involve the surrounding communities in decision-making processes. It is likely that the degree of concern and desire for involvement will depend upon the public's perception of the scale of the potential impacts beyond the Fermilab site. The perceived impacts will reflect not only the physical presence of surface support buildings, but also uneasiness with having a particle accelerator underneath the neighborhood, even if it is a few hundred meters deep. A resolution of these concerns will require good communication with the public, public involvement in the process of developing a site for a new facility and flexibility to address public concerns in the design.

Many of the perceived concerns have already entered Fermilab's consciousness and have influenced the discussion in this document. A near-surface construction of a linear collider traversing the Fermilab site is not expected to be feasible—hence investigation of a design in a deep tunnel with minimal surface presence. The geologically preferred siting of a very large hadron collider may not be achievable because of the surface population density—hence investigation of the implications of tunneling outside the optimal geology.

Next Steps/Conclusions

Many outstanding issues need to be addressed before any of the facilities could be brought to the stage of a concrete proposal upon an identified site. In particular, the three facilities described in the report share a need for complete technical designs, for further definition of utilities requirements and assessment of available infrastructure and capacity, for planning on how to navigate the NEPA/EIS process, and for public outreach and involvement. Facility-specific issues to be confronted would include further evaluation of the optimum accelerator circumference and exploration of impacts of tunneling in non-optimal geology in the case of the VLHC, and evaluation of the near-surface siting to achieve vibration level criteria in the case of the linear collider.

This report does not attempt to identify a preferred forefront facility that could represent the future direction of Fermilab. Neither does it attempt to identify a preferred site for each specific facility, with the possible exception of the neutrino factory. Rather, recognizing that site identification for a linear collider, a neutrino factory, or a very large hadron collider is at best several years away, this report identifies and analyzes potential representative sites. It demonstrates that options exist to support the conclusion that Fermilab could serve as an excellent host for any of these facilities.

Appendix A

CHARTER

Fermilab Committee for Site Studies
December 1, 1999

Purpose

With the completion of the Main Injector Project, the laboratory is now in a position to begin looking forward to potential new projects that may be suitable for construction on, or in the vicinity of, the Fermilab site. While there are many different ideas for new accelerator facilities, any machine built at Fermilab will have some common aspects such as tunneling techniques, enclosure construction, utility support, component handling and installation, environmental impacts, and the need for public outreach. The purpose of the Fermilab Committee for Site Studies will be to identify these common elements, to explore new ideas in these areas, and to identify opportunities for cost minimization and functional optimization. This committee will serve as a collection point for available information in these common areas and thus avoid redundant effort on the part of individual project collaborations.

In addition to the identification of common elements of individually proposed projects, the committee will also have the responsibility to characterize the Fermilab site and surrounding areas, noting advantages and limitations with respect to possible accelerator facilities. Existing infrastructure and utility availability, physical and/or environmental limitations of the current Fermilab site, opportunities for extension of facilities beyond the existing site, and availability of laboratory resources and support should be reviewed and evaluated.

There are several resources currently available to the committee from which information can begin to be collected. These include the 1996 NLC Site Study as well as the Main Injector and NuMI Project documentation and work done for the original proposal to construct the Superconducting Super Collider (SSC) at Fermilab.

Committee Membership

The Deputy Head of the Facilities Engineering Services Section will chair the committee. Membership will include the Head of the Facilities Engineering Services Section and representatives from each of the projects currently being explored--the Next Linear Collider (NLC), the Very Large Hadron Collider (VLHC), and the Muon Collider/Neutrino Source. In addition representatives from the ES&H Section and the Office of Public Affairs as well as experts for various specific aspects of the committee's work will be asked to participate. Specific areas of expertise could include tunneling, geology, conventional construction, environmental issues, installation and maintenance, utility support, community relations, and structures. Depending on specific areas identified, additional subcommittees may be formed to focus effort on a particular topic.

Responsibilities and Reporting

The committee will report to the Associate Director for Accelerators and the Associate Director for Operations Support. The Committee Chair and the Associate Directors will determine the details of reporting requirements. The Associate Directors will be responsible for managing any funding that will be used to support the work of the committee. The initial charge to the committee will include the following specific tasks:

- Identification of common elements and suggested approaches in all currently identified potential new projects with a focus on tunneling, enclosures and infrastructure.
- Identification of external interests that will be affected by plans for future Fermilab facilities both on site and beyond the existing Fermilab boundaries. Planning for appropriate timing and means of communication and information exchange with potentially affected parties.
- Characterization of the Fermilab site and surrounding areas with respect to potential new accelerators, and exploration of both advantages and limitations of possible specific facility layouts.
- Identification of existing infrastructure, both on the Fermilab site and in the surrounding area, and potential application to a new facility.
- Establishment of communication with the SLAC civil design group for the purpose of establishing a common framework for evaluation of NLC designs.
- Documenting the work of the committee in summary form by the end of FY2001.