Superconducting RF R&D at Fermilab

11/10/06 S.N. (sec 5, sec 6 & summary modifications)
1/03/07 SM (Modifications to SRF sections with input from Task Leaders)
1/3/07 Modifications by RDK

Introduction

Superconducting Radio Frequency technology (SCRF) cavities represent a key “enabling” accelerator technology that provides high accelerating gradients structures for future accelerators. The International Linear Collider (ILC), a new energy frontier High Energy Physics machine is being designed using this technology. The technology also is useful electron linace to drive Free Electron Lasers (FEL) and for intense proton sources needed for long baseline neutrino physics, neutrino factories or muon colliders. SCRF cavities have additional applications in heavy ion accelerators and for energy recovery linacs for electron cooling of beams. The reduction in length in superconducting linacs is expected to generate new applications to medical accelerators for proton and neutron therapy, and for creating radio-nuclides for medical diagnostics.

The ability to consistently master the production and processing of high-gradient SCRF cavities and to achieve this at a reasonable price is crucial in the future construction of these large scientific devices. Fermilab is heavily engaged and making strong technical contributions to the ILC R&D program. Regardless of where the ILC is built, the U.S. will get an opportunity to contribute to the construction of high-tech components such as the SRF cavities. In total, the number of cavities required for the ILC is approximately 17,000, constructed over a four year period.

Currently the best process for producing high gradient SRF cavities involves electron beam welding of deep drawn high purity Nb components into cavities then producing very smooth interior surfaces with a technique called electropolishing(EP). In the U.S. SRF cavities have been fabricated and electropolished successfully at national laboratories such as TJNL and LANL and universities such as Cornell and MSU but very limited cavity fabrication experience and no processing experience exists in U.S. industry. In contrast, both Europe and Japan have developed the technology to fabricate and process cavities in industry and industrial capabilities are well advanced.

It is expected that U.S. industry must play a large role in the fabrication of the mass produced cavities and cryomodules for ILC. However, it is also likely that industry will not make the large financial investments in SCRF cavity fabrication and processing facilities in advance of ILC project approval. Similarly, the technology and infrastructure to test SCRF cavities is extensive and beyond that which can be expected from U.S. industry. The timescales and technical knowledge required to operate these facilities necessarily mean that they must be developed at large national laboratories working closely with U.S. SCRF capable universities and with international partners. As expertise and capability grows, the technology can be transferred to U.S. industry when adequate funding is available. . SCRF technology in general is technically challenging and success in the U.S. will require close cooperation of the U.S. national laboratories and U.S. industry and considerable investment. The process for when and how U.S. industry will be engaged in this activity is still under discussion and is largely beyond the scope of this document. One possible model for execution of the ILC is to build the required infrastructure at National labs and that industry would bid to use these facilities

.The assumptions in the remainder of this document are that: 1) the U.S. will choose to participate in ILC and contribute 1/3 of the required ILC main linac components, 2) that SCRF fabrication and processing infrastructure will initially be built at national laboratories and that labs and industry will work closely together in the R&D program; the location of production fabrication and processing equipment is left as a question to be answered, 3) that all test infrastructure for U.S. produced cavities and cryomodules will be located at national laboratories. 4) that the U.S. cavity and cryomodule R&D program in the near-term is well integrated with the goals of the GDE, and 5) that prior to a decision to construct the ILC, or as an early stage of and ILC project a test linac of 5-10 ILC RF units will be built in the U.S. to validate project costs and technical performance.

The focus of this document is on Fermilab's plan and aspirations in SCRF R&D for the next ~3-4 years. It should be understood that this document represents our current but evolving strategic vision vs a fixed long-term plan to build a facility. This is an R&D effort. Plans should and will evolve both because more technical information will become available, because circumstances and timescales for ILC or other projects like HINS may change, and based on recommendations from national and international advisory bodies.

The Fermilab SCRF program is intended to be a part of a larger U.S. effort requiring continuation of and expansion of existing partnerships and optimal use of SCRF facilities already in place with other national laboratories such as ANL, TJNL, LANL, and SCRF capable universities such as Cornell, MSU, UW, etc. while at the same time preparing Fermilab as a possible host site for ILC.

The main thrust of Fermilab ILC Accelerator R&D program is to establish U.S. technical capabilities in Superconducting Radio Frequency (SCRF) Cavity and Cryomodules. Fermilab near term objectives include determination of cavity processing parameters to produce cavities that achieve accelerating gradients of 35 MV/M with high yield, development of and intellectual understanding of the processes that limit current cavity gradients and reproducibility, and development of test facilities to validate performance of cavities and associated cryomodules. Our plan is to work closely with U.S. Industry to engage them in both the fabrication of cavities and eventually the surface processing and cleaning. The assumption is that all testing of cavities and cryomodules will occur at national laboratories.

The GDE goal for ILC cavities is ~95% yield at 35 MV/M after two process/test cycles. To reliably establish these yields requires several hundred process/test cycles on a time scale of a year or two for identical cavities processed in an identical fashion. In addition we assume a steady flow of additional R&D cavities in parallel both to qualify cavity and processing vendors and to explore innovations in fabrication and processing. This vision sets our goal of being able to process at Fermilab about 100 cavities per year. We believe that this capacity when augmented by other U.S. SCRF institutions will allow ILC to settle on an acceptable process and yield in a few years. It is worth noting that in a model in which 1/3 of ILC cryomodules are built in the U.S., the peak cryomodule production rate would be 200/yr corresponding to ~1700 cavity process and test cycles per year. Thus the proposed infrastructure represents ~10% of the eventual capability needed during the construction of the ILC. The Illinois Accelerator Research Center (IARC) would increase this capacity to about 1/3 that needed for ILC. (More on IARC later in this document)

The scope of the planned SCRF infrastructure at Fermilab described in this document is then set by two requirements:

1) The need to produce and process cavities in sufficient quantity to develop and verify the process yields at an accelerating gradient of 35 MV/M for ILC.

2) The requirements set by a Main Linac test facility with a sufficient number of RF units to establish operational experience, determine component reliability, and serve as a development test bed for RF feed-back, controls, cryogenics, instrumentation, and a host of measurements requiring beam. It is our belief that scope of the test facility will need to be ~ 1% of the final ILC main linacs and thus would require approximately 7-10 ILC RF units. (Where each RF unit consists of 3 cryomodules, one 10 MW klystron, one Modulator, and the associated RF distribution and control system). We note that the components for some these RF units may come from abroad.

It is important to note that although the scope of the planned facility is set by the needs of ILC, the facility is generic in nature and would be equally useful to produce an intense proton source or the electron linac for a light source. Similarly, it is also important to note that much of the cost of the R&D program specific to ILC (e.g. cost of cavities, cost of cavity processing, specific equipment purchases, facility operation expenses, etc) is funded from other sources and is not discussed in this document which focuses on infrastructure. In some cases the decision as to where to assign costs is not black and white. For this reason we have chosen to describe and cost the full infrastructure required without regard to how this infrastructure is funded.

The assumed capacity of the proposed SCRF infrastructure would be sufficient to verify yield of a particular process recipe in less than one year and sufficient to provide the cavities and cryomodules for the main linac test facility in about two years. It is assumed that the cavities and cryomodules produced by this infrastructure will be a mix of objects produced first by Fermilab in collaboration with ILC institutions and later by US industry. It is our intent that this infrastructure will also be used to transfer these technologies to the US industries and may in fact be operated by industry as they gain experience.

Fermilab has made requests to the DOE for many years. However, prior to the technology choice for ILC, the DOE was slow to fund SCRF R&D at FNAL. Indeed the requests in this document include much of the infrastructure requested in the SMTF proposal to DOE in 2004. After the technology choice for ILC initiated the construction of SCRF infrastructure appropriate for ILC at FNAL using FY05 funding. This effort continues in FY06 and is expected to continue in FY07 and beyond. Significant progress has been made in the development of infrastructure at Fermilab, yet the total M&S funds expended thus far are a small fraction of that required and funding has significantly slowed our progress. Significant resources are needed both at FNAL AND at other U.S. SCRF capable institutions. Only this way can we build modern SCRF facilities that will be on par with other regions. The infrastructure and cryomodules built for TTF at DESY were estimated at 126 M euro ($150 M) using European accounting which only includes M&S expenses. The infrastructure required first in ILC R&D phase and then later to qualify the U.S. as a viable host of ILC will extend well beyond that employed for construction of TTF. The plans for the first 3 objectives stated above are described in the document "Cavity and Cryomodule R&D Priorities and Plans at Fermilab", submitted to ILC-GDE R&D Board.

1. Cavity Fabrication

Fermilab is working to develop US industry for Cavity Fabrication. At present Fermilab is working with one US industrial partner and plans to develop 2 more in FY07. We propose to upgrade Fermilab's existing SCRF test facilities and build new ones so that we can develop inhouse expertise and efficiently work with industry in technology transfer.

The Niobium for cavity fabrication is purchased from industry. Fermilab at present operates one of the two eddy current scanners in the world to perform Quality Control (QC) checks of Niobium sheet used for cavity fabrication. We plan to continue this activity while training industry. Two additional eddy current scanners will be needed for higher throughput QC of the Niobium sheets that will received from vendors prior to its use for cavity fabrication. These scanners will be used to check niobium sheet material for pits, scratches or inclusions of foreign material prior to use in forming cavities.

Fermilab needs a limited in-house cavity fabrication capability to develop and refine cavity fabrication techniques. Such a capability would allow us to fabricate R&D cavities in a timely manner and transfer welding technology to new cavity fabrication vendors. We propose to purchase one properly sized and configured electron-beam (EB) welding machine for this purpose. An in-house EB welder also serves to insulate the R&D program from dependence on industrial EB welders not currently under our control. We have already had one experience in which the EB welder we were using was sold to another vendor and was unavailable for many months. In other cases significant schedule delays have resulted due to available weld dates on industrially owned machines. Fermilab would maintain this welder and make it available to prospective new cavity vendors allowing them to get into the business without the large investment in money and staff required by a modern EBW machine.

Fermilab will develop infrastructure for clean cutting and forming of the Niobium for the cavity dumbbells, end tubes and HOM. Prior to welding, cavities parts require etching and cleaning to avoid weld contaminates. We plan an area at FNAL equipped with two chemical exhaust hoods and acid chillers. A class 100 clean room with ultrasonic cleaning tanks, rinsing/drying benches and ultra pure (UP) water system is required for degreasing cavity components before welding.. It is possible that improved cavities may be fabricated with blanks cut from high purity Nb billets (large crystal or single crystal) vs fine grain rolled Nb sheets. If so we will need to purchase appropriate cutting tools (wire EDM or diamond saws). This will be part of the cavity processing infrastructure described later in this document

Cost Summary: (In $k)

Infrastructure	M&S (direct)	SWF (direct)	Total with Indirect
Cavity Infrastructure	$ 3,000	$ 675	$ 4,375

2. Cavity Processing Facility (CPF)

To achieve reliable production of high performance cavities this effort will couple processing and performance tests in a tight-loop program to determine which parameters or processes lead to the current observed variability in cavity performance. Eventually, the procedures developed with this R&D program will be industrialized. The process we imagine is that labs develop the processes first with industry looking on and using that equipment for training, then industry builds its own equipment and demonstrates that it can achieve acceptable results.

In the tight-loop program bare cavities are chemically processed and vertically tested over and over again until the desired gradient is repeatedly achieved. The goal is to develop a specification and reproducable proceedures for the chemical processing. It must be demonstrate that the design gradient can be repeatedly produced. The high yields (95% in two attempts) means that a statistically significant measurement requires process number of cavities that is ~ 100 for each recipe explored. Since more than one recipe may have to be explored in the next few years, extensive infrastructure is needed. It is our plan to build the required infrastructure in the U.S. such that by working closely with national and international partners the ILC goals can be achieved. As the only remaining HEP lab in the U.S. beyond 2009 its is clear that Fermilab must shoulder a large piece of the required U.S. cavity processing infrastructure. In parallel we plan to establish Fermilab's technical capabilities in SCRF. Success will have been achieved when we can demonstrate high yield with a specified set of process steps using U.S. infrastructure. When success has been achieved, we will work with our laboratory and university partners to use this same infrastructure to transfer this technology to US Industry. To achieve these goals, (essentially those of the GDE S0/S1 task force) the proposed cavity processing capacity of the FNAL infrastructure facility has been sized to process about 100 cavities per year.

The process steps to repeatedly achieve 35MV/m require great care and excellent record keeping and quality control procedures. Within the CPF, cavities are chemically processed, cleaned, and assembled for vertical test. After vertical test, cavities are returned to CPF where successfully tested cavities are dressed with helium vessels and prepared for horizontal test. Cavities which fail vertical test are reprocessed at CPF and returned again to vertical test until design gradient is met.

The CPF will include Buffered Chemical Processing (BCP) and Electro-polishing (EP) to produce smooth RF surfaces, High Pressure Rinse (HPR) stations to remove particulates from cavity surfaces, vacuum furnaces to remove hydrogen and for low temperature bake, cavity tuning equipment to remove cell to cell variation and achieve field flatness, cavity initial QC, and other infrastructure and equipment to support these elements and other R&D. We also plan to purchase equipment and explore Tumble Polishing (CBP) as an alternative process that could substantially reduce the volume of hazardous acids required to remove the ~100 micron thick layer damaged during Nb sheet rolling and cavity forming.

Work flow of the cavity processing and testing is outlined in Figure 2.1. Fig. 2.2 shows a schematic layout of the Cavity Processing Facility. Work station and infrastructure elements required for a coherent facility design are listed and described below. Summary cost estimates are provided at the end of this section. Detailed breakdown of cost estimates are provided in a separate attached spreadsheet.

Major infrastructure & systems of the CPF are outlined below:

Chemical and Mechanical Polishing Stations

Electro-Polish (EP), Buffered Chemical Polishing (BCP) cabinets will be housed in a room equipped with an exhaust ventilation system. Cabinet quantities as required to process 100 cavities per year are shown in the table. Cavity interior surfaces are etched by EP to remove surface contaminants embedded into the niobium. Cavity exterior surfaces are etched using BCP to prepare the cavities for hydrogen removal baking. Tumbling stations will be available for mechanical polishing of cavities as described above.

Chemistry Lab

The chemistry lab will be used for small sample preparation and R&D. Weld prep BCP etching will also be done here.

Chemical Cooling System

This is an auxiliary system for the chemical polishing infrastructure. The system pre-cools acid for electro-polish (EP) and also dissipates heat generated during chemical

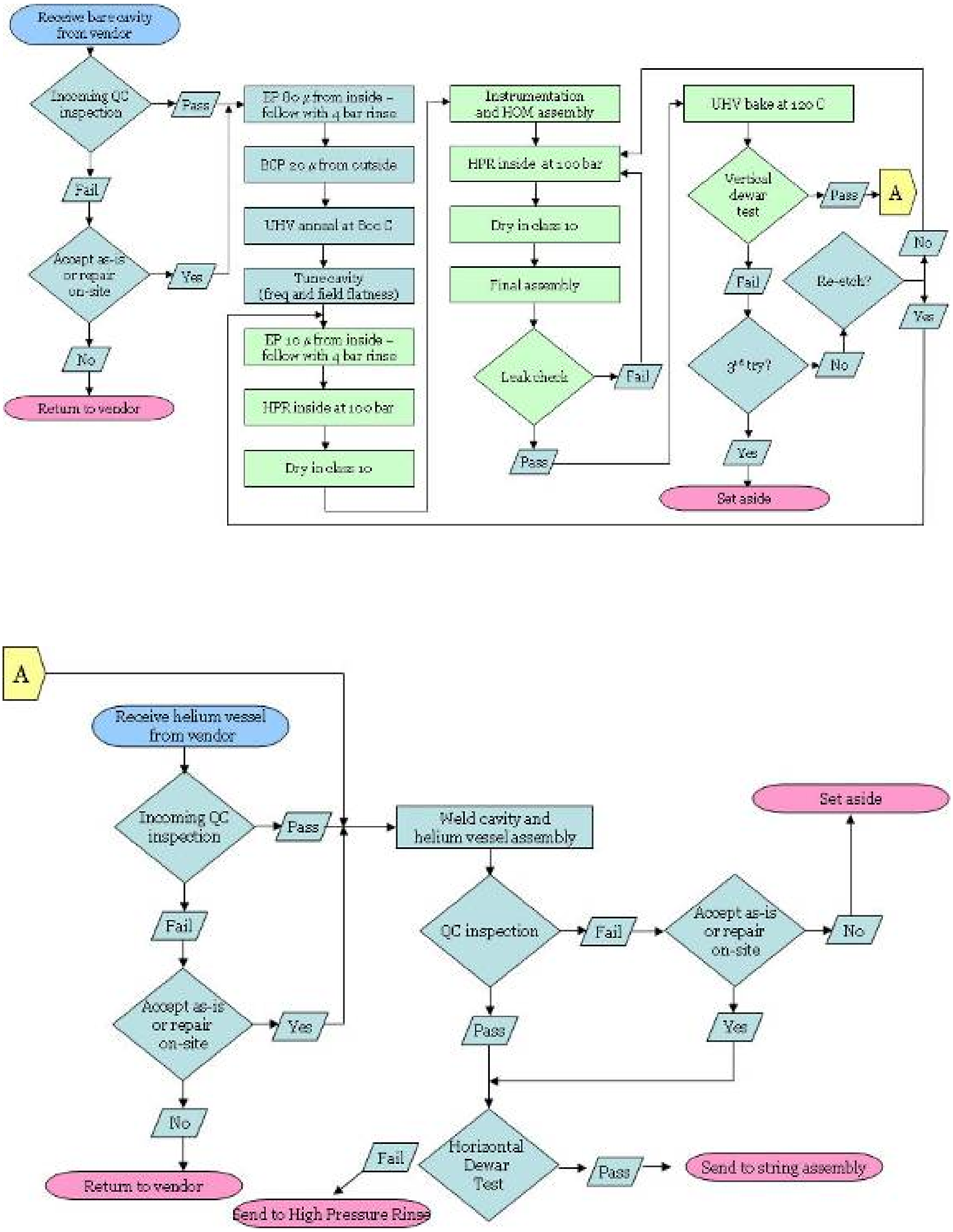

Figure 2.1: Cavity Processing & Testing Workflow

processing. This cost of this system is included in ‘Chemistry storage, preparation, treatment infrastructure’ item in the attached spreadsheet.

Chemical Storage Building

A stand alone building adjacent to the CPF will store acid safely away from facility operators. Acid is stored in double wall drums in storage cabinets connected to the scrubbed ventilation system. The storage cabinets will include a means to cool the acid and shall be integrated with the EP and BCP tool control system to allow pumping and possibly mixing of the acids for the process. This cost is included in ‘Chemistry storage, preparation, treatment infrastructure’ item in the attached spreadsheet.

Clean Room – Class 10

After HPR, the cavities must be dried and sealed in a Class 10 clean room before being transported to vertical area. The clean room will have 600 ft^2 of floor space, double-wall construction, individual fan filter units and a perforated raised floor. The cost includes consultant fees, procurement, installation, and commissioning. The cost estimate is based on the clean room recently installed in CAF-MP9 for the cavity string assembly work.

Clean Room – Class 1000

The High Pressure Rinse cabinets, RF Inspection and Tuning Area, Wet Station, Vacuum furnaces, and cavity storage racks will be housed under the roof of a 1500 ft^2 Class 1000 Clean Room. The clean room will bridge the chemistry area and the Class 10 Clean Room, providing a controlled space within the larger industrial building environment for the more sensitive cavity processing activities. The RF Inspection and Tuning Area will be an enclosed room within the larger clean room area to allow tight control of temperature (+/- 1C) and humidity (+/- 5%RH) required for proper RF measurements and tuning. Class 100 zones will surround HPR units and Wet Station.

Exhaust Fume Scrubber

During the EP and BCP processes, several gaseous species are generated including: hydrogen, sulfuric acid, nitrogen dioxide, hydrofluoric acid, and nitric acid vapors. For personnel safety and to control facility airborn emissions to an environmentally acceptable level, an Exhaust Fume Scrubber is required. Scrubber cost is included in ‘Chemistry storage, preparation, treatment infrastructure’ item in the attached spreadsheet.

High Pressure Rinse Stations

After the final electro-polish (EP), it is necessary to perform a high pressure rinse (HPR) to wash any acid residues and airborne particles from the cavity’s internal surface. Three HPR stations will be installed in a soft-wall Class 100 section of the Class 1000 Clean Room, directly adjacent to the Class 10 clean room. The pass through design of the HPR cabinet will allow loading of cavities from a Class 1000 area and unloading of clean cavities directly into the Class 10 clean room for drying and further assembly.

Neutralization System

To comply with Illinois EPA and local government regulations, acidic rinse water is processed before discharging to municipal waste water systems. Water is pH-neutralized and fluoride ions bound to complexant molecules before reaching the sewer system. This cost is included in ‘Chemistry storage, preparation, treatment infrastructure’ item in the attached spreadsheet.

Furnaces
After initial degreasing and etching, bare cavities are baked at 800C under full vacuum for ~5 hrs vacuum in a vacuum furnace to remove dissolved hydrogen gas. Two front-loaded units with molybdenum hot zone, uniform temperature distribution, dry roughing vacuum pump and cryo or turbo high vacuum pump for vacuum, transformers, and ancillary equipment will be procured. Two low temperature furnaces will be procured for 150C bake of dressed cavities.

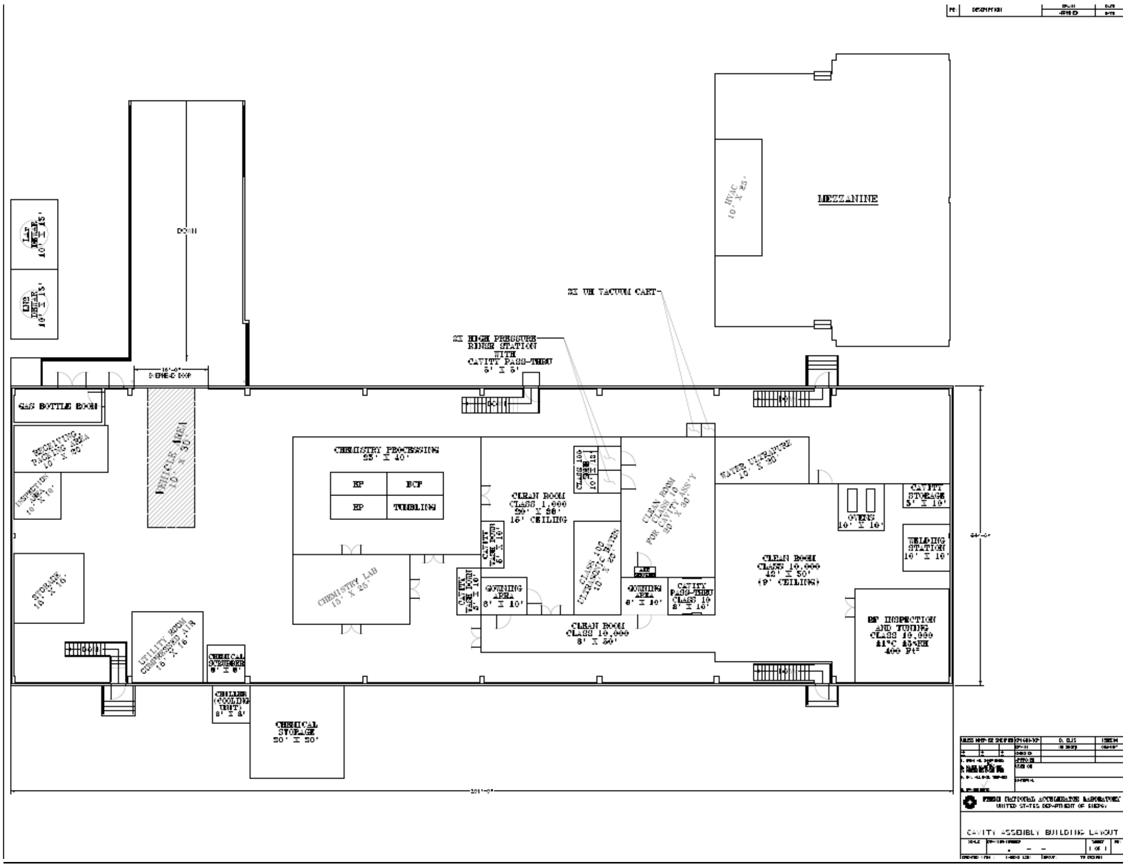

Fig 2.2 Schematic Layout of the Cavity Processing Facility

RF Inspection and Tuning Area
A laboratory for Radio Frequency (RF) measurements and warm tuning of bare cavities is needed for tuning the cavity for field flatness. Major infrastructures for this lab are an automated bead-pull device and mechanical cavity cell tuning machine, a network analyzer, and other miscellaneous fixtures and equipment. Temperature and humidity control is critical for accurate and repeatable cavity tuning.

Ultra Pure Water System
Ultra-pure water (UPW) is required for high pressure rinse of cavities, rinse of acid from processed cavities, and ultrasonic bath and rinse stations. The UPW system includes the

purification skid (reverse osmosis and deionization) and distribution. It is designed for redundancy, allowing continued operation for any single failure of the critical components. UPW distribution system requires extensive monitoring and testing (TOC, bacteria etc.) to provide specified quality of water to the above mentioned stations.

Vacuum Pump Down and Leak Check Carts

Ultra-pure high vacuum pumping and leak checking carts are needed to provide the required vacuum for the cavities. The cavities require ultra high vacuum (UHV) practices and particle-free flange connections to perform with high gradients. Dry oil free rough pump and turbo high vacuum pump carts are required for the UHV. The pump carts have a leak detection filament for helium leak checking of the cavity flange connections. Airborne particle free electropolished vacuum connection lines are required to assure the particle-free vacuum pumping. Power fail safe valves are required to prevent any particle contamination during a power outage.

Welding Station

TIG orbital welding machines in a glove box are needed to weld the helium vessel to the bare niobium cavities during the dressing of the bare cavities. Several welding stations and welding fixtures will be procured.

Wet Station

Cavities and associated hardware and tooling are cleaned with ultra-pure water. A number of ultrasonic tanks and a rinse cabinet with a hand-held spray wand will be procured. The station will include drying racks and HEPA units to allow drying of components in a Class 10 environment.

Misc. Utilities

Compressed Air – Instrument Grade

Dry, particle free compressed air shall be available in the building to operate pumps and valves. The compressed air system requires dual compressors, air dryers, and filter banks for proper redundancy.

Gaseous Nitrogen and Argon

Boiled-off cryogenic nitrogen and argon gas micro bulk Dewars will be installed. The gas distribution will be an ultra-pure gas delivery system. The lines will be 316 electropolished stainless and all the fittings will be VCR connection with nickel or stainless steel gaskets. The gas distribution lines will be orbital welded in a clean room and installed using particle-free practices.

House Vacuum

A regular house vacuum cleaning system is required. A back stream restrainer will be installed.

Cavity Handling Carts

The bulk of cavity handling within the facility is accomplished using specialty carts designed for this activity. The carts safely and securely transport cavities from station to station and include lifts for raising and rotating cavities into test and condition positions. Cart costs are included as 'Miscellaneous Equipment and Fixtures' in Table 1.

Summary:
Fermilab's CPF will occupy approximately 12000 square feet. This includes an allowance for hallways and office space. Our plan would be to refurbish an existing FNAL building for this purpose.

Cost Summary: (In $k)

Infrastructure	M&S (direct)	SWF (direct)	Total without Indirect
Cavity Infrastructure	$ 11,100	$ 4590	$ 15,690

Detailed cost breakdown is provided in a companion spreadsheet to this document.

3. Vertical Cavity Test Facility (VCTF)

A vertical cavity test facility (VCTF), for CW RF vertical testing of bare ILC 1.3 GHz superconducting RF (SCRF) cavities, is being designed and built at Fermilab's Industrial Building 1 (IB1) in FY06-FY07. The VCTF fulfills several important roles at Fermilab. The primary purpose of the test facility is to measure the performance of cavities, both as a study of their production and processing and as an acceptance test prior to insertion in a cryomodule. Another very important purpose is to allow Fermilab scientists and engineers to develop experience using SCRF technology, and contribute to the world's effort to understand and apply it to new projects. Eventually the test facility will be made available for technology transfer to industry, university groups, and other laboratories. Finally, it is an important tool for validating ILC project costs and technical performance. This facility is being built with significant cost savings and faster implementation with respect to a brand new facility, because of the existing cryoplant and infrastructure located in Industrial Building 1 (IB1) at FNAL (currently the home of the FNAL Magnet Test Facility).

The VCTF has been designed for SCRF cavity tests measuring Q vs. T down to approximately 1.5 K, and Q vs. E_{acc} at 2 K, for a cavity power dissipation of up to 250 W[1]. The facility currently under construction consists of a single vertical test stand (VTS). The cavity cooling will be provided by the existing IB1 cryoplant, which is capable of delivering LHe to the test stand at a peak rate of 700 liters/hr and maintaining a bath temperature of 2K with up to 125 W of continuous power dissipation. (The power dissipation can be increased to 250 W for short periods of time without an excessive increase in bath temperature.) The RF system is based on that from the Jefferson

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[1] For a Tesla-style 9-cell 1.3 GHz cavity, $P_d = (1.04 \times 10^{-3}) * E_{acc}^2/Q_0$, where P_d is the cavity dissipated power [W], E_{acc} the gradient [V/m], and Q_0 the unloaded Q factor.

Laboratory vertical test facility, modified for 1.3 GHz operation and taking advantage of technology advances. Cavities in the cryostat will be magnetically shielded, to avoid increasing surface resistance due to trapped magnetic flux in localized normal-conducting surface impurities. In addition, cavities will be radiation shielded, to maintain a safe work environment. The x-ray and neutron radiation is generated by field-emitted electrons traveling in the cavity RF fields and impacting the cavity inner surface and other material in the cryostat. The radiation shielding is designed to maintain the "controlled area" status of IB1. Both the magnetic and field-emission effects are interesting technical challenges affecting SCRF cavities, and can be optimally characterized and studied at Fermilab due to the existing talent pool of scientists and engineers with relevant experience.

The civil construction in the VCTF for one VTS was completed in August 2006, and a cryostat order was placed in September 2006. The cryostat design is shown in Figure 3.1. Designs for the RF system and test stand cryogenic system are complete and most items have been purchased. The radiation shielding design is complete, with the mechanical detail design and procurement in progress, and consists of three parts: a plug internal to the dewar, a movable shielding lid, and the concrete walls of the pit. The radiation shielding lid design is shown in Figure 3.2. The layout of the VCTF, including one VTS, the planned instrumentation racks and control room, is shown in Figure 3.3. By the end of FY07, the VTS will be complete and operational.

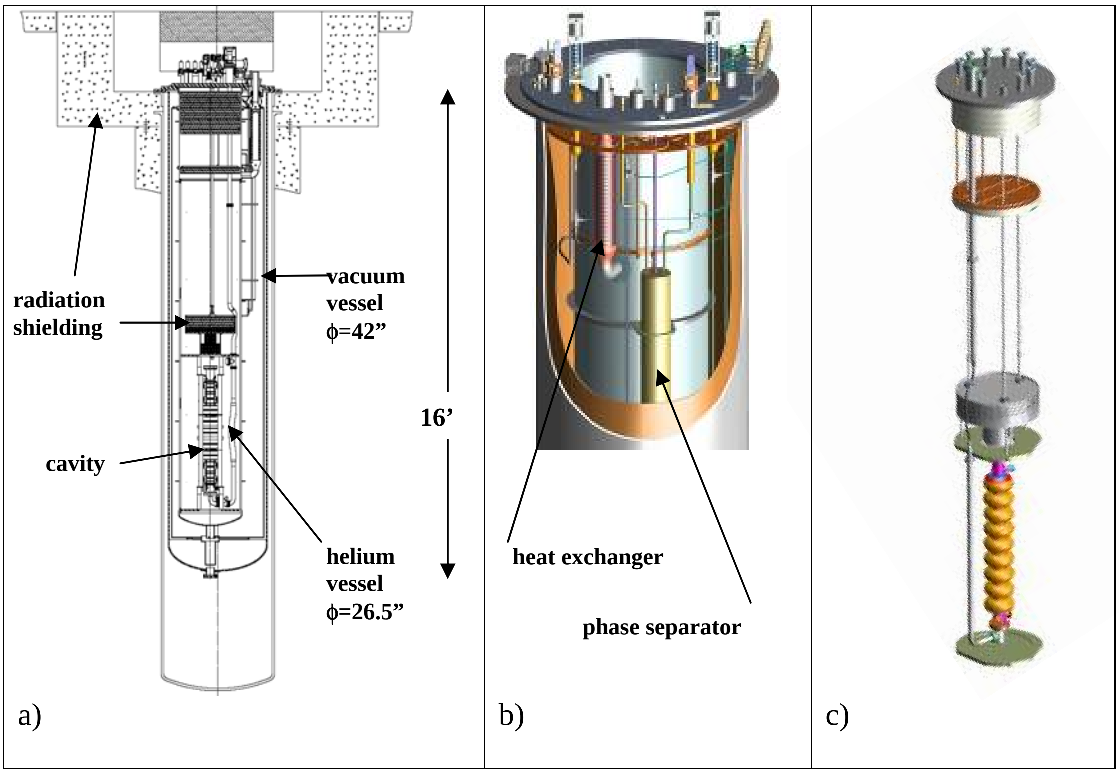

Figure 3.1: (a) Cryostat design showing vacuum vessel, helium vessel, and a single cavity insert. A portion of the radiation shielding is also shown. (b) Cutaway drawing showing the heat exchanger and phase separator, and (c) Top plate assembly with cavity and radiation shielding insert attached.

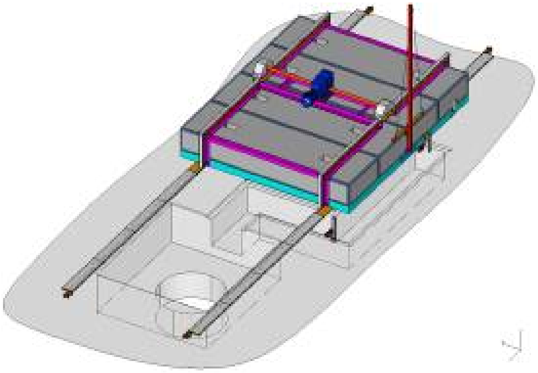

Figure 3.2: Mechanical design of the radiation shielding lid. The light blue on the bottom is steel, and the gray blocks are concrete with steel frames. The lid is moved over the pit for RF testing.

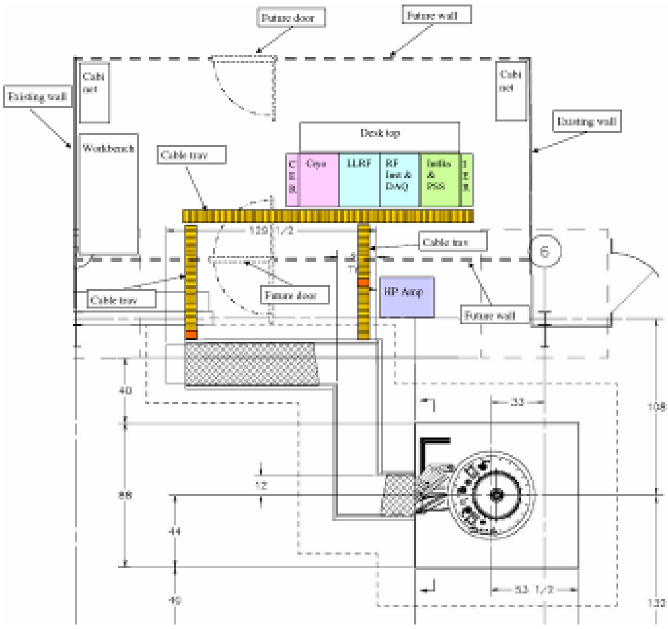

Figure 3.3: Layout of the VCTF, including one VTS cryostat, instrumentation trench and cable trays, and control room.

For FY08, the VTS capability will be expanded to provide a major U.S. contribution to the global GDE/R&D task force S0 testing plan. In Fy07 we will explore the capability and cavity throughput of the VTS, train personnel, and establishing operational procedures. In FY07-08 we plan to build addition VTS stations to increase the cavity throughput.

A typical VTS test cycle, defined as all steps from the moment a cavity arrives to IB1 for testing until it leaves the building, with the current IB1 infrastructure and support staff, is expected to take on average 5 days. An analysis of expected system downtime implies a maximum throughput of ~48 cavity tests per year with the initial VTS station. This initial throughput is not expected to be sufficient to support the R&D and pre-production test needs of the ILC program at Fermilab. Therefore, we also present a plan to increase vertical test throughput.

Inserting a second cavity into the test cryostat, and RF testing each cavity individually, is expected to be the single most effective way of increasing the test stand throughput. Because the RF portion of a cavity test is projected to take less than 10% of the total test cycle duration, substantial time can be saved by cooling down and warming up both cavities together. With all other factors remaining the same, we estimate that the 5-day test cycle is extended to 6 days by adding a second cavity because of the additional RF test time and cavity handling time. Significant effort has been made to accommodate a two-cavity configuration in the VTS, in all aspects which do not negatively impact the VTS completion schedule. The test cryostat has been designed to fit two cavities end-to-end. The existing top plate design has provisions to accommodate separate connections for each cavity to the top plate for RF and vacuum. Because the radiation shielding design process is complex and time-consuming, the adequacy of the existing shielding design for the two-cavity configuration will not be determined before the VTS radiation shielding procurement. Nevertheless, it should be possible to RF test a second cavity with minimal upgrades to the shielding. A typical two-cavity VTS test cycle with the current IB1 infrastructure and support staff is expected to take on average 6 days. Including estimates of system downtime, a maximum of ~80 test cycles can be supported in a year.

Additional cavity throughput can be achieved by building additional cryostats and a top plate staging area. Two more nearly identical vertical test stands will fit in the available space in IB1, sharing a common radiation shielding lid. Figures 3.4 and 3.5 show a conceptual 3-D model and layout, respectively, of the VCTF with two additional VTSs and a staging area. RF testing will still occur for only one cavity at a time. As mentioned previously, this is not a strong constraint because RF testing is only 10% of the total VTS test cycle. The same RF and DAQ system (with the exception of the power amplifier) is multiplexed among all three VTS cryostats. The power amplifier is not multiplexed, because it has to be in close proximity to the cryostat top plate to avoid excessive losses. The staging area is sized to accommodate up to six top plates, each supporting two cavities. Each two-cavity insert can be prepared while the previous one is still undergoing a test cycle. To minimize design SWF cost, additional VTS cryostats will be nearly identical to the first one. However, some design features may change either to increase throughput, or to optimize radiation shielding. Increasing the number of VTSs to three, each testing two cavities, and with the existing IB1 infrastructure and support staff increases the VTS throughput to a maximum of ~180 cavity tests per year. However, building additional cryostats requiresthe following cryogenic infrastructure upgrades. Otherwise the throughput will be significantly limited by system downtime.

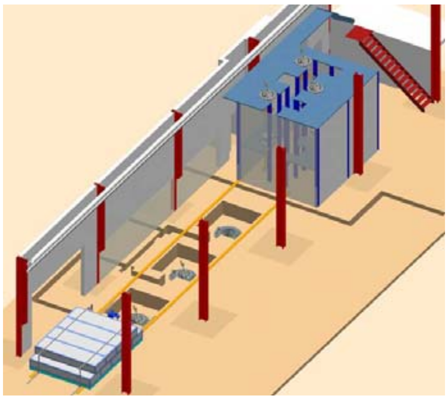

Figure 3.4: Conceptual design of two additional vertical test cryostats (foreground) and a top plate assembly staging area.

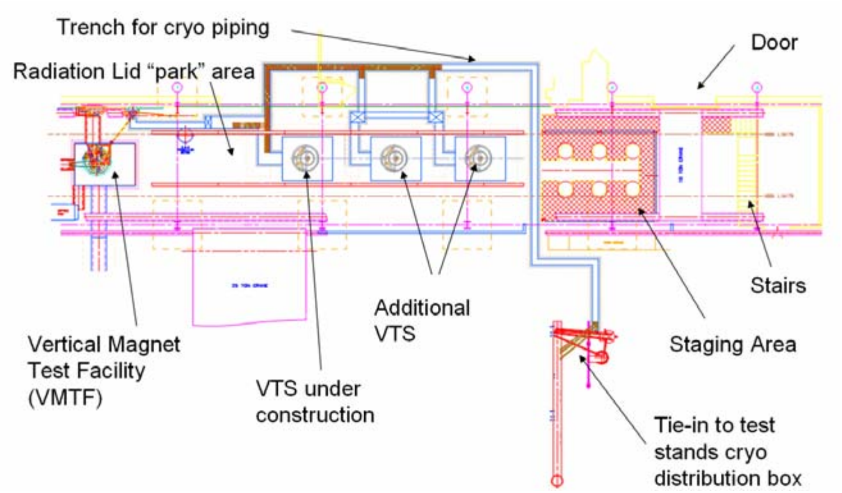

Figure 3.5: Conceptual layout of VCTF, including staging area, instrumentation trenches and cable trays for three vertical test stand cryostats.

Figure 3.6 shows the tie-in of the single VTS cryostat to the IB1 cryogenic infrastructure. Additional cavity throughput and schedule risk reduction can be obtained by improving the existing cryogenic infrastructure. These improvements address three issues, given in order of priority.

1. *Reduce schedule risk by adding safeguards to reduce downtime*.

Install a compressor/purifier skid at the outlet of the vacuum pumps to eliminate contamination from sub-atmospheric operations only (the main source of contamination due to air leaks). A compressor is needed to increase the efficacy of purification from the absorber beds by increasing the He pressure. Note that virtually all new cryoplants are built with full flow purifiers, while the IB1 cryogenic system has a partial flow purifier that can only purify 10 to 20% of the cold box inlet flow. The vertical test stands at both Jefferson Lab and DESY/TTF use full flow purifiers.

2. *Decouple VTS cavity testing from superconducting magnet tests.*

The vacuum pumps for VTS are currently shared with the magnet test facility, and the resulting interference between magnet and cavity tests is expected to cause scheduling inefficiency. Installing a dedicated vacuum pump for the VTS will eliminate this strong coupling, permitting superfluid magnet testing to proceed in parallel with cavity testing. In addition, a new dedicated 10-ton crane will decouple crane use from the VMTF.

3. *Reduce schedule risk by adding helium gas storage capacity to avoid limiting test duration.*

The helium gas storage capacity of the IB1 cryogenic system is limited to approximately 55% of the maximum LHe storage capacity. An upper limit of 150 psia on the buffer tank pressure is necessary to maintain control of the compressor skid pressures via the gas management system. Once this pressure limit is reached, testing must be halted regardless of the liquid inventory to re-liquefy helium and lower the buffer tank pressure. The addition of two more 30,000 gallon buffer tanks will increase gas storage volume and allow the cryogenic system to support longer periods of testing.

A new 13.8kV/480V transformer will be required for either item 1 or 2 to accommodate the increased power consumption. Additional support staff will also be required to take full advantage of the infrastructure upgrades; however, the cost of this additional staff is not included in the current cost estimates.

The proposed IB1 cryogenic infrastructure upgrades are shown in Figure 3.7. Increasing the number of cryostats to three, each equipped with two cavities, and implementing all of the proposed IB1 infrastructure and manpower upgrades increases the VCTF throughput to a maximum of ~264 cavity tests per year.

The summary of expected cavity throughput for several infrastructure scenarios, given in terms of the number of cavity tests, and including an analysis of system downtime, is shown in Table 3.1. The standard two-shifts per day and seven-days per week cryosystem operation have been included in the VTS test cycle duration estimates. A cost estimate of the proposed upgrades is shown in Table 3.2, assuming the SWF cost per FTE is 135 $k, M&S overhead is 0.3098, and SWF overhead is 0.1650.

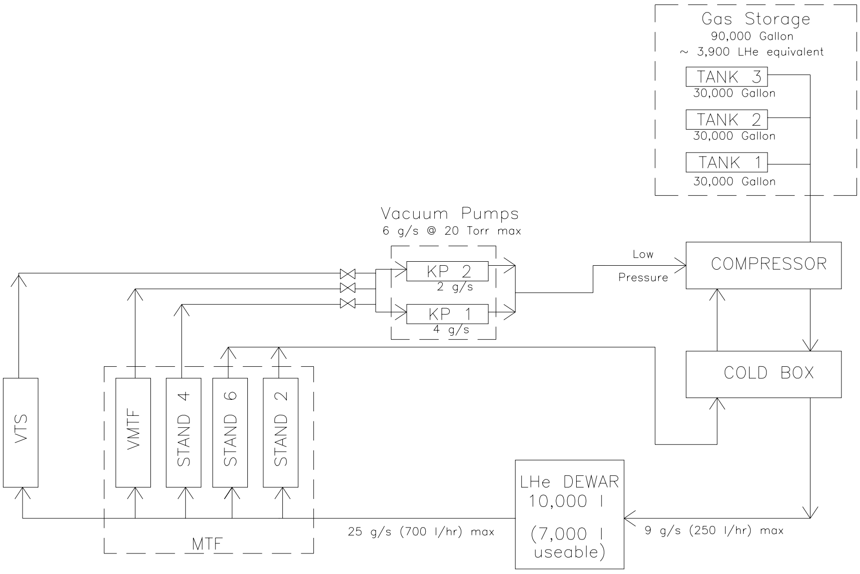

Figure 3.6: Single VTS integration into existing IB1 cryogenic infrastructure.

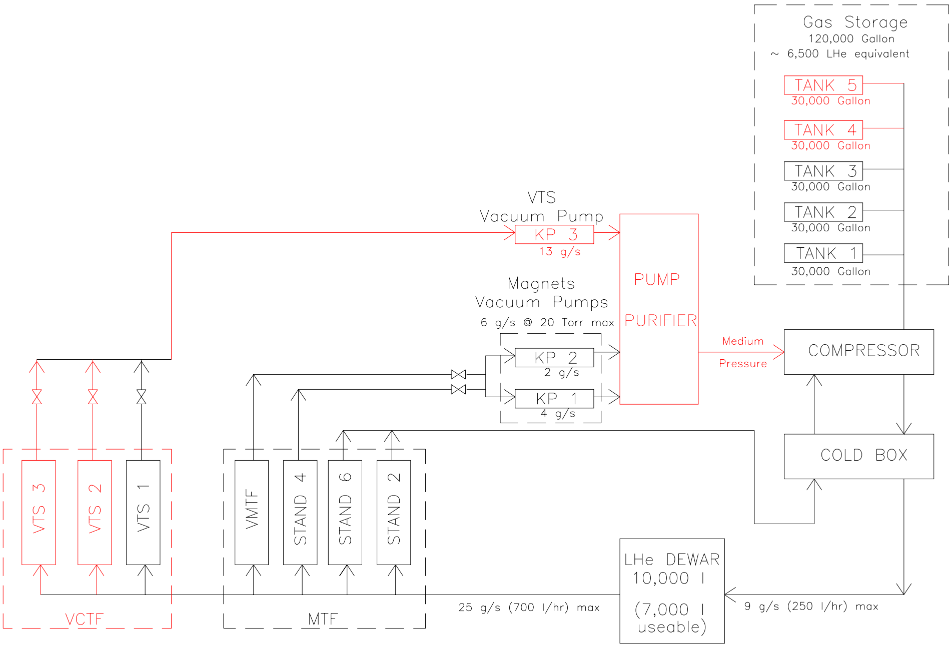

Figure 3.7: Proposed 3-VTS system with cryogenic infrastructure upgrades.

Table 3.1: Expected cavity throughput for several VCTF infrastructure scenarios, given in terms of the number of cavity tests, and including an analysis of system downtime.

Scen	IB1 Cryo system status	as-is	upgrade

#VTS cryostats	1		3	1		3
#cavities in all available VTS cryostats	1	2	6	1	2	6
Downtime cause						
Cryo down	60	60	90	45	45	45
Pumps unavailable	24	24	36	0	0	10
LHe supply unavailable	12	12	20	0	0	10
VTS unavailable	15	15	25	15	15	25
holidays	10	10	10	10	10	10
Total down days	121	121	181	70	70	100
VTS test cycle	5	6	6	4	5	6
# tests	**48**	**80**	**180**[2]	**73**	**118**	**264**

Table 3.2: Cost estimate (k$) of the proposed upgrades.

Infrastructure	M&S (direct)	SWF (direct)	Total without Indirect
Cavity Infrastructure	$ 2625	$ 1845	$ 5588

4. Horizontal Test System (HTS)

After a successful vertical test an individual cavity is sealed in its helium vessels and fully “dressed” with couplers and tuners. The dressed cavity is tested with high pulsed RF power in a Horizontal Test System designed to cool the cavities to 1.8 K. The purpose of these horizontal tests is to verify that the cavities can achieve the desired accelerating gradient and Q_0 in order to qualify them for assembly into a cryomodule. Such tests are currently required to separate effects associated with cavity dressing from those associated with cryomodule assembly. Currently all cavities are horizontally tested before they are incorporated into a cryomodule. This is likely to be the case for at least the next 3 years. The longer term goal is improve the yield of these processes so that < 10% of the ILC production cavities need be tested in an HTS. Another important use of the HTS is as single cavity test bed to develop tuners, couplers, LLRF electronics, etc. with pulsed RF power. These sort of developmental tests are in competion with “production” qualification of cavities for cryomodules. The construction of one HTS (“ILCTA_MDB”) is underway in the Meson Detector Building and should be ready for operation by the end of FY06. (see Figure 4.1) A second HTS is planned. This second HTS will be based on

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[2] This scenario carries considerable risk because of the lack of a purification system to remove contamination introduced by three sub-atmospheric test stands. The cryogenic system downtime could be considerably higher than estimated.

the ILCTA_MDB design but will include a larger cryostat capable of testing two dressed cavities simultaneously. The additional capacity is needed to increase the throughput. At present it takes roughly one week to perform full power test of a cavity in HTS at DESY. (ie 50 cavities per HTS system per year assuming no down time) Our initial plan is to test all the R&D cavities in HTS. This would mean about 100 tests per year (two HTS systems) if all HTS were successful. We current plan for 3 HTS stations (one single system, one two cavity system) but as noted above, the HTS systems must also serve a test beds for development of couplers, tuners, and LLRF systems and cannot be dedicated to just production testing.

Figure 4.1 Cryostat for first HTS system under construction

The HTS cryostats will reside in shielding caves in the Meson Detector Building designed to contain X-ray radiation from the cavities. An important reason for siting the HTS in the MDB is that a large cryogenic system already exists in the building and this system has already be modified to deliver 2K refrigeration by the addition of a large vacuum pump skid (Figures 4.2 and 4.3) Use of this existing infrastructure has both shortened the schedule for SCRF operations and reduced the initial capital expenditures.


Figure 4.2 Large Vacuum pumps at MDB


Figure 4.3 Part of the new Cryogenics infrastructure at MDB

Two ion-pump systems will provide the clean vacuum needed for the cavity and its input coupler, and a turbo-pump system will provide the cryostat insulating vacuum. Faraday cups will measure dark currents. RF power will be delivered by a 1.3 GHz klystron capable of at least 1 MW driven by a low-level RF system based on a DESY design. We currently plan to use a small 300 KW klystron and modulator system for the 1st HTS system. (Figure 4.4) However that system will need to be upgraded to include a more powerful modulator and klystron. Klystron choices are under discussion, the only viable candidate at this time is a 3.3 MW single beam klystron made by Thales. Data from measurements at the HTS will be logged and entered into a permanent cavity database.

Figure 4.4 Small modulator and klystron at MDB

Cost Summary for HTS (in $k)

Infrastructure	M&S	SWF	Total with Indirect
HTS Infrastructure	$ 1,220	$ 1,055	$ 2,805

5. Cryomodule Assembly Facility (CAF)

Dressed cavities must next be incorporated into cryomodules for use in accelerators. The current ILC design employs two cryomodule types, one with 8 dressed nine cell cavities and a quad package and a second type with 9 cavities and no quad. The current plan for HINS is an 8 GeV accelerator with 7/8 of the machine constructed from beta = 1 cryomodules essentially identical to the ILC cryomodules. It is likely that any future machine based on elliptical SCRF cavities would use similar cryomodules. Our plan has been heavily influenced by the DESY infrastructure. Our plan is essentially to build an upgraded version of the infrastructure in DESY Hall 3 for cavity dressing, cavity string and cryomodule assembly. Our plan is to assemble this facility in an existing Fermilab building (MP-9) and the Industrial Center Building (ICB) in the Technical Division. The use of existing building results in considerable cost and schedule savings. The ultimate throughput of this infrastructure was set by both preproduction needs of ILC and of a project of the scope of HINS. We set this capacity to be oned assembled cryomodule per one month. (12 cryomodules per year) using single shift operation.

Cryomodule Assembly Workflow

Cryomodule assembly workflow planned at both CAF buildings is outlined below:

At CAF-MP9:

- Receive chemically processed bare cavities
- Dress cavities for horizontal dewar test:
    - Weld the titanium (or perhaps Stainless) helium vessel to the bare cavity
    - Install cold part of the main coupler in the Class 10 clean room
    - Install tuner and magnetic shielding
    - Send cavity for horizontal dewar test
- Received dressed cavities from horizontal dewar test
    - Proceed to string assembly if the desired gradient is achieved
    - High pressure rinse cavity if the desired gradient is not achieved and return for HTS retest
- Assemble qualified dressed Cavities to form a String in the **Cavity String Assembly Area** (Clean Room)
- Install String Assembly to Cold Mass in the **Cold Mass Assembly Area at CAF-MP9**
- Transport the Cold Mass from **CAF-MP9** to **CAF-ICB**

At CAF-ICB:

- Receive partially assembled cold mass from CAF-MP9
- Install the Cold Mass on the Cold Mass Assembly Fixture in **Cold Mass Assembly Area at CAF-ICB**
- Align Cavity String to the Cold Mass Support
- Attach additional components, instrumentation, radiation shielding, etc. to complete cold mass
- Install the String assembly with the cold mass into the Vacuum vessel in the **Vacuum Vessel Assembly (Big Bertha)** area
- Ship Completed Cryomodule to **NML for testing**

Each of these steps is described in more detail below.

Cavity String Assembly:

A series of clean rooms are needed to assemble dressed (welded with helium tank around the bare cavity), horizontal tested and qualified to gradient cavities into a cavity string that consists of 8 cavities and a BPM (beam position monitor) / Quad magnet package. The string assembly procedures require venting already chemically processed, gradient qualified and evacuated cavities to an inert gas atmosphere in order to interconnect them with bellows between each cavity and gate valves at each end of the string.

The cavity string assembly clean rooms infrastructure consists of:

- Class 1000 ante clean room for preparation of the dressed cavities for transportation into the assembly clean room.
- Class 10 assembly clean room where the cavities vacuum is vented to interconnect them.

Class 10 means that there are 10 particles (size of 0.5 micron) flowing through one cubic foot of air in the clean room per minute. A typical industrial production floor has ~250,000 particles for comparison. The clean room cleanliness requirements are provided with HEPA and ULPA fan filter units (FFU) circulating / filtering the air inside the room with an approximate velocity of 90 feet per minute. The floor of the clean room is raised and perforated in order to allow for through air circulation (laminar flow) without any air break up (turbulence). The laminar air flow, FFUs, air handling / HVAC equipment and state of the art construction material are the main pillars of a clean room infrastructure.

A large clean room was specified and procured in early part of FY06 at Fermilab for about $ 1 M. The clean room has a Class 10 assembly area with the size of 60 ft long and 12 ft wide. This is needed to be able to assemble a cavity string (8 cavities, BPM/Quad package) that is approximately 36 ft long. (See Figure 5.1)

Figure 5.1: Cavity String Assembly Clean Room

A rail under the clean room raised floor holds the cavity support fixture and cavities during assembly. The rail also facilitates the transportation of the assembled string out of the clean room for next assembly station. (Cold Mass Assembly Area, non clean room). (See Figure 5.2)

Figure 5.2: Rail system with cavity support stands (Cold Mass Assembly Area at CAF-MP9)

Cryomodule Assembly Facility (CAF) at Fermilab consists of 2 buildings: CAF-MP9 (see Figure 5.3) and CAF-ICB (see Figure 5.4). CAF-MP9 houses the string assembly clean rooms, the rail for string assembly under the clean room extending to the cold mass assembly area and the cold mass assembly fixture adjacent to the clean room.

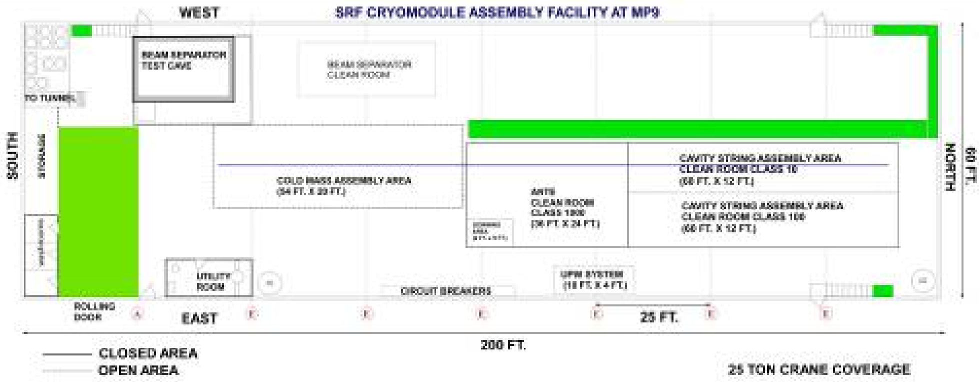


Figure 5.3: CAF-MP9 Layout

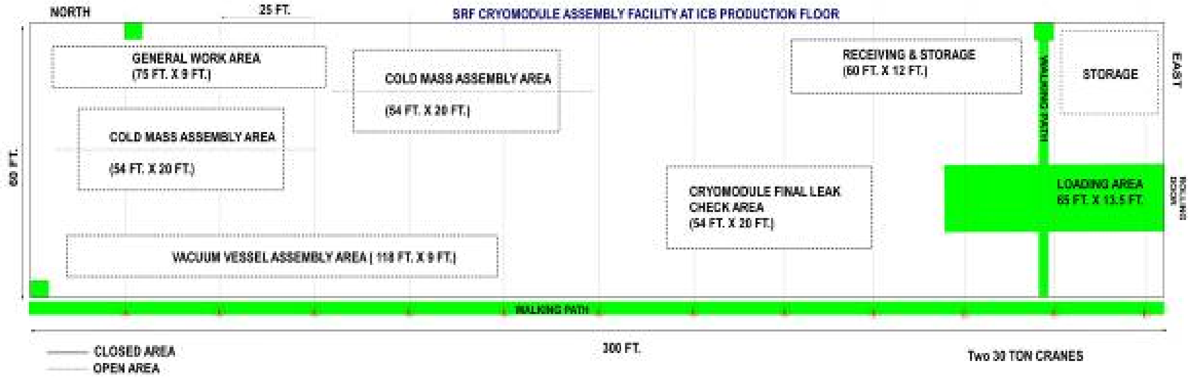


Figure 5.4: Planned CAF-ICB Layout

Cryomodule Assembly Facility (CAF) in MP9 is now largely complete. However, additional smaller clean rooms are needed for individual cavity work, High Pressure Rinse systems must be built, and extensive fixtures are still to be procured:

String Assembly Fixtures: There are approximately 30 fixtures used to assemble a string for a TTF type III+ cryomodule. Major fixtures are cavity support stands, components alignment fixtures etc. (See Figure 5.5)

Figure 5.5: Cavity Support Posts

Vacuum / Ultra Pure Gas Flow Equipment/ Hardware: The cavities need to be backfilled and argon flow is needed during interconnecting them with bellows. All the vacuum and gas handling equipment need to be clean room compatible, particle free in order not to contaminate the cavities during assembly.

Ultrasonic Cleaner: It is necessary to clean outside surfaces of the cavities, fixtures and assembly hardware for particle reduction before they are transported into the Class 10 assembly area. (See Figure 5.6)

Figure 5.6: Ultrasonic cleaner to clean outer surfaces of the dressed cavities

UPW Infrastructure: Ultra pure, De-ionized water is needed for the ultrasonic cleaning of the parts.

Cavity Handling Cart / Fixture: Dressed cavities needs to be transported as needed inside Class 10 assembly area. This cart needs to be clean room compatible.

All of this equipment basically fills the MP9 building. We require additional floor space for the final assembly of the cryomodules. We have chosen to put this space in the industrial center building which was used for similar assembly of LHC quadrupole magnets. Our plan is to transport the assembled string with the cold mass support from MP9 to ICB before it is aligned.

CAF-MP9 will continue to be the main CAF building for the assembly of the ILC cavity strings in the clean room in the coming fiscal years. After the installation of the horizontal test stand at Fermilab, the Joint BCP Facility at ANL and the planned Cavity Processing Facility (CPF) at FNAL, Fermilab plans to process and dress cavities. (Currently, bare cavities are purchased from industry and are processed at collaborating institutions.)

We plan to procure and setup TIG welding stations at CAF-MP9 to dress cavities:

- Receive chemically processed and Vertical Tested Bare Cavities at CAF-MP9
- TIG Weld Helium Vessels to the Bare Cavities
- Leak Check

After the welding of the helium tank, the dressed cavities need to go through several cycles of high pressure rinsing (HPR). We plan to design and install 2 state of the art High Pressure Water Rinse systems at Cavity Processing Facility at FNAL. Until this facility is ready, we plan to install an HPR system at CAF-MP9.
Then the dressed cavities will be moved into the Clean Rooms for the assembly of the cold part of the power coupler in preparation for the horizontal test. The assembly of the cold part of the power coupler requires venting the cavity inside to inert gas atmosphere so the assembly work needs to be done in the Class 10 Clean Room.

After the assembly of the cold part of the main coupler, then dressed cavities will be moved out of the Clean Room and it will be further dressed for the horizontal test at CAF-MP9. The tuner and the magnetic shielding will be installed for the test. Then the cavities will be shipped to Meson Detector Building (MDB) where the horizontal test stand infrastructures reside.

If the horizontal test result is successful and the desired operating gradient is achieved, then the dressed and qualified cavities will be brought back to CAF-MP9 for assemble of the cavity string which was explained above.

If the test result is not satisfactory, dressed cavities will go through several cycles of HPR at CAF-MP9 and it will be retested.

Below is the additional planned infrastructure estimated cost of CAF-MP9 cavity dressing infrastructure:

Infrastructure	M&S	SWF	Total with Indirect
Cavity String Assembly	$ 330	$ 101	$ 517

Cold Mass-Vacuum Vessel-Final Cryomodule Assembly

After the cavity string is picked up off the rail and aligned to the cold mass support, the cold mass assembly is moved to Vacuum Vessel Assembly Area of CAF in the Industrial Center Building (CAF-ICB). Transport fixtures will be required to move the cavity string from MP-9 to ICB. We note that this differs from the DESY approach in which the cryomodule assembly takes place in one building. However, moving the string to ICB before alignment when it is least sensitive to the move does not seem to represent a large risk. However, it allows us to bring considerable infrastructure and floorspce to bear on the completion of the cold mass assembly eliminating one potential bottleneck in the CM throughput. The major CM assembly fixture used in this assembly area is “Big Bertha”, a cantilever fixture used to support the cold mass for the remainder of the insulation and power coupler assembly and then slide the vacuum vessel on the assembled cold mass. (see Figure 5.7) One fixture was ordered in FY06 and a second is planned for FY08. Portable clean rooms for coupler assembly and specialized vacuum and leak detection equipment will be required.

The cold mass assembly major steps are:

- Position / Align the string under the cold mass support
- Interconnect cavity helium supply pipes
- Install tuners on the cavities
- Install instrumentation on the cavities
- Install magnetic shielding on the cavities
- Lower the cold mass support to the cavity string
- Install the needle bearings and bearing housings
- Pick up the cavity string off the rail with the cold mass support through the needle bearings housing
- Align cavity string to the cold mass support

Figure 5.7: Big Bertha was procured in FY06

Additional cold mass assembly steps at the Vacuum Vessel Assembly Area include:

- Move the cold mass assembly to Big Bertha Fixture
- Install and weld 4K aluminum shields
- Wrap 10 layers of MLI
- Install and weld 80K aluminum shields
- Wrap 30 layers of MLI
- Slide vacuum vessel onto the cold mass
- Align the cold mass inside the vacuum vessel
- Assemble the warm part of the power couplers
- Harness the instrumentation / read out wire, cables
- Install and solder power leads for Quad magnet

As stated before, Cryomodule Assembly Facility at Fermilab consists of two assembly buildings: CAF-MP9 and CAF-ICB. CAF-MP9 will accommodate the string assembly and part of the cold mass assembly infrastructure. CAF-ICB will accommodate remainder of the cold mass assembly and vacuum vessel assembly infrastructure. Approximately $100K is needed to clean and prepare the ICB building for CAF-ICB. Planned expendures include costs to remove of existing equipment and fixtures from the building, costs to clean & coat the production floor, and costs for general refurbishment to improve the cleaniness of the workspace)

The major infrastructure/ fixture and equipment outside of the clean room for the Cryomodule Assembly are funded in FY07. Our plans assume that we will have $0.7 M total (direct) to complete these tasks in FY07.

With additional improvements CAF can also be used for small scale mass production assembly area for cryomodules and would be appropriate for a project like HINS where the number of cryomodules is small. Similarly, with the fixture/ tooling listed at the above table, ILC R&D quantity preproduction cryomodules can be assembled at CAF and the facility can serve to train industrial cryomodule vendors.

Throughput Assumptions:

The current infrastructure installed at CAF-MP9 and that planned to be installed at CAF-ICB in FY07 has a throughput appropriate for R&D quantity cryomodule fabrication. (about1 cryomodule per 3 months) However, will relatively modest upgrade throughput can be increased to 1 CM/month single shift or 2 CM/month with double shift operation.

The assumptions used for this estimate are:

It takes 10 shifts to assemble a cavity string in the clean room. This equals to 5 business days if two 8-hour shifts are worked per day, or a throughput of 1 cavity string per week could be assembled in the CAF-MP9 Clean Room. We have 1 rail system underneath the clean room; therefore having multiple string assembly lines is not a viable option to increase the throughput for the cavity string assembly.

It takes 12 business days to assemble the Cold Mass out of the clean room in the Cold Mass Assembly Area and 9 business days for the final assembly on the Big Bertha fixture in the Vacuum Vessel Assembly Area. These effort corresponds to 21 eight hours shifts.

In order to achieve a throughput of 2 cryomodule per 1 month:

- With one crew work two 8-hour shifts in the Cavity String Assembly Clean Room to assemble cavity string. This will assure 1 assembled string every week (5 business days). This comfortably allows two string assemblies per month including staging and cleanroom down time.
- Move the assembled string from CAF-MP9 to CAF-ICB as soon as possible (preferably right after the string is rolled out of the clean room) in order to have part / material transfer access to the clean room for the next string assembly.
- Have two parallel Cold Mass Assembly Lines at CAF-ICB with two crews to receive assembled cavity strings from CAF-MP9 every week.
- Work two 8-hour shifts in each Cold Mass Assembly Area. This effort should produce 2 cold mass assembly on average every 21 business days.
- Have 2 parallel Big Bertha Fixtures in the Vacuum Vessel Assembly Area at CAF-ICB.
- Work two 8-hour shifts in the Vacuum Vessel Assembly Area with the same crews. These crews should take 9 business days to finish ~2 cryomodules each month.

This throughput assumes that components and trained personnel are available all the time to assemble the cryomodules.

If one wants to achieve this capacity, the following additional infrastructure will be needed for CAF, especially for CAF-ICB:

Infrastructure	M&S (direct)	SWF (direct)	Total without Indirect
Cold Mass Assembly	$ 360	$ 169	$ 640

Cost Summary

Cavity dressing infrastructure will be procured and installed at CAF-MP9 in early FY08 until the planned Cavity Processing Facility (CPF) is ready. The summary of total cost for the Cryomodule Assembly Facility at MP9 and ICB is

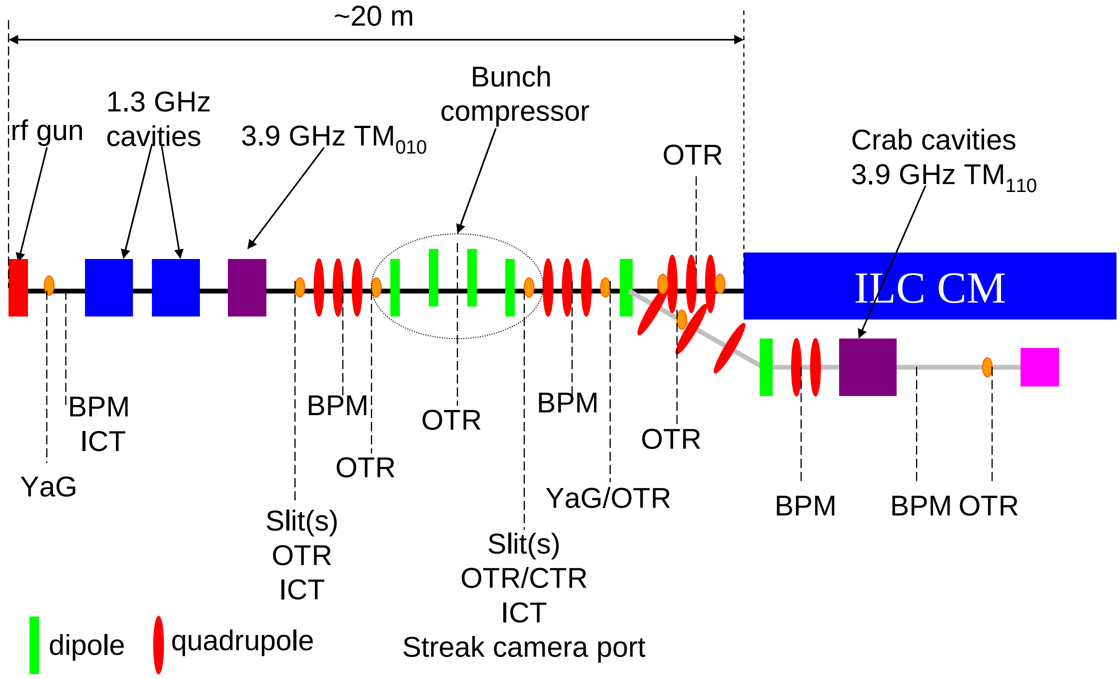
Infrastructure	M&S (direct)	SWF (direct)	Total without Indirect
CAF	$ 690	$ 270	$ 1158

6. RF Unit Test Facility at New Muon Lab (ILCTA_NM)

The Tesla Test Facility (TTF) at DESY has provided a valuable system test for many elements of the TESLA SCRF technology. However, several important changes to the TESLA design are being planned for the ILC. These will include a higher cavity gradient, relocation of the quad, shortening of the cavity end-group, and a new tuner design. Such changes will likely be introduced in several steps, with the first one being called a Type-IV cryomodule design. Also under discussion are different modulators, klystrons, cavity shapes, and other things. The minimum size system test needed to confirm the performance of such a new design is a single RF unit (3 cryomodules) with an ILC-like beam. As many tests are statistical in nature, a larger test or multiple tests are likely to be required.

Presently, Fermilab is building an ILC RF unit test facility using an existing FNAL building (the “New Muon Lab” or NML). The facility at NML will be the only U.S. facility capable of testing completed cryomodules. In 2007, the facility will initially serve as a CM test stand capable of testing the first ILC-like cryomodule assembled at FNAL, without beam but at high accelerating gradients. The facility then will be completed in FY08 to permit CM testing with an ILC-like electron beam. The NML will perform the initial tests of all U.S. built ILC cryomodules built in the next four or more years and thus will make a major contribution to the GDE ILC global R&D effort. The goal is to produce a single RF unit (two Type-III+ and one Type-IV cryomodules) by end of FY09, and a complete RF unit, made up of Type IV (or higher) cryomodules, by about a year later. This facility will be invaluable to the ILC R&D program leading up to and most likely through the ILC construction. It will allow for a dedicated study of dark currents, HOM extraction, alignment, LLRF and control issues, cryogenic issues, RF power distribution, reliability and system recovery issues, crab cavities etc. Although the ILC program will be the first user of this facility, it is not going to be the only user. As the need for ILC-related tests diminishes, the facility will start serving to other users, such as HINS or Advanced Accelerator R&D projects and experiments.

The NML facility will consist of (1) the electron injector area (approximately 20 m long), (2) the accelerator area, comprised of 1 or more cryomodules (approximately 40 m) and (3) the test beam lines area. The existing New Muon building will need to be extended in order to accommodate the electron injector, the 3 cryomodules and the test area. Initially, a temporary cryogenics system will be installed in the building. This interim cryosystem will not be capable of supporting the ILC-like mode of operations for a full RF unit at full ILC repetition rates. A new cryogenics plant (described in Section 7) will be added to the facility. The following is a brief description of NML facility stages and areas. The electron injector is schematically shown in Figure 6.1.



The electron injector area

Figure 6.1: The NML electron injector schematic.

The electron injector is the backbone of the NML facility. It has to provide an electron beam with tunable parameters (bunch length, number of bunches per macropulse, transverse emittance, etc…). It will also incorporate diagnostics (e.g. bunch length and emittance measurement) to characterize the beam prior to its injection in the cryomodule(s). A tap off beam line, located downstream of the bunch compressor, can redirect the beam in an off-axis beamline for crab cavity or other tests. The electron injector will be based on the normal-conducting (n.c.) L-band photo-cathode rf gun. Since 1992, Fermilab has been engaged in the production of high-brightness electron beams. In conjunction with the TESLA collaboration, it constructed and operated an L-band (1.3 GHz) photo-cathode rf gun, a copy of which was installed at the TTF in DESY Hamburg, for various tests, especially for the proof-of-principle UV SASE free-electron laser experiment. The TTF gun was later upgraded with a new rf gun. Fermilab has recently obtained all documentation needed to produce this new upgraded rf gun. This rf gun will be procured, commissioned and installed at the NML in FY08. It is schematically shown in Figure 6.2.

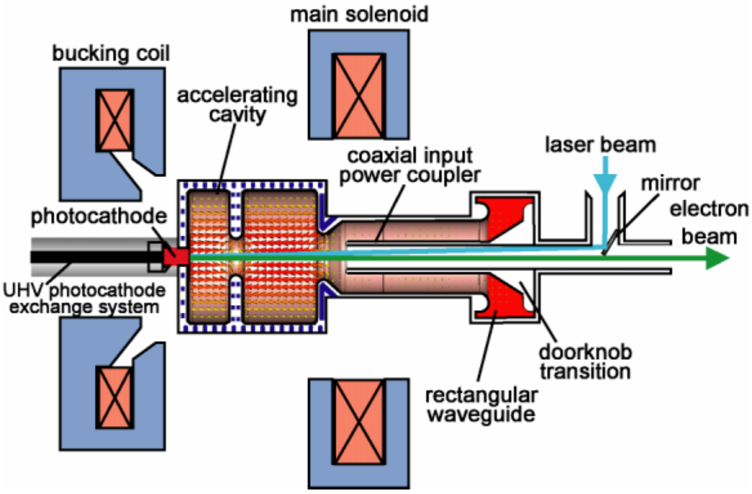


Figure 6.2: Schematic of the n.c. RF photo gun.

The existing Fermilab/NICADD photo-injector (except for rf gun) will be moved to the NML and will be upgraded with several elements as shown in Fig. 6.1. Thus, the initial NML injector will consist of a new rf gun, two existing TESLA cavities (one operating at 12 MV/m and one at 25 MV/m), a magnetic chicane bunch compressor, a focusing channel, and an energy spectrometer magnet, which also permits crab cavity tests. This configuration requires a high-power klystron/modulator system (~4-5 MW) for the normal conducting rf gun, and two low-power systems (~300 kW nominal each) for the two TESLA style capture cavities. Both the gun and the modulator would allow for a long pulse (1 ms) operation at a 5 Hz rate. Table 6.1 presents a summary of NML injector parameters:

Table 6.1: The NML electron injector parameters

# Electrons/bunch	2×10^{10}
# bunches/train	up to 3000
Bunch repetition rate	3 MHz
Train repetition rate	up to 5 Hz
Average current	50 µA
Beam energy	40 MeV
RMS bunch length	0.3 – 6 mm
Normalized rms emittance	4-5 µm

A further step would incorporate two (or three) 3.9 GHz cavities of two different designs, presently under development. One of these cavity types, operating on the TM_{010} mode, (refer to as 3rd Harmonic) is used to linearize the longitudinal phase space (doing so enhances the peak current as the beam get compressed in the downstream bunch compressor). The other two operate on the TM_{110} mode and impart a time-dependent transverse kick on the bunch. These two cavities will be use to mimic the proposed ILC crab cavities setup, and as a diagnostics to measure beam properties of different sub-picosecond time slices within the bunch. The cavities require ~4 kW power. To implement these two (three) cavities requires two (three) additional low power modulators; one of which is similar to what needed for the individual TESLA cavities (above), and one that is a gated CW modulator.

The work on the NML injector and the crab-cavity test beamline encompasses several formal and informal collaboration efforts with the following institutions:
DESY (rf gun, LLRF);
INFN-Milano (photo-cathode system);
NIU (injector design);
Rochester University (laser);
Argonne (controls);
SLAC (rf power, crab-cavities, controls);
The Cockcroft Institute – Daresbury (crab-cavities).

The accelerator area

The Accelerator area will initially consist of a single Type III+ DESY cryomodule. This cryomodule will be assembled at Fermilab in the spring of 2007 and delivered to NML in July, 2007. Figure 6.3 shows the schematic layout of the NML facility at this stage.

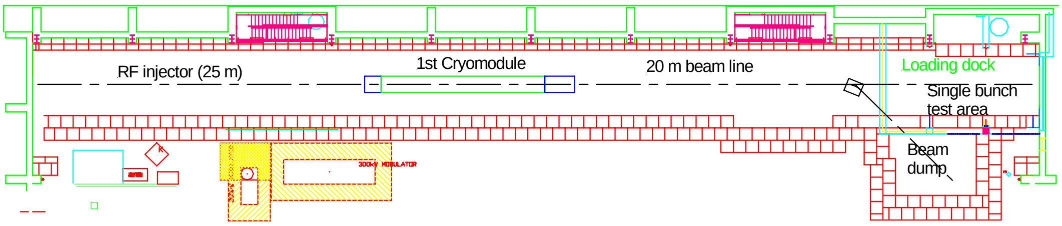


Figure 6.3: A schematic layout of the NML facility at its initial stage. The existing building has a 73m x 18m below-grade floor area available for installation. Not shown

on this sketch are various klystron, laser hut and "stay clear" areas on the floor of the building and the cryogenic refrigerator.

The second Type III+ cryomodule, the first with U.S. processed cavities, is scheduled to be delivered to NML in the summer of 2008. Figure 6.4 shows a schematic layout of the NML at this second stage.

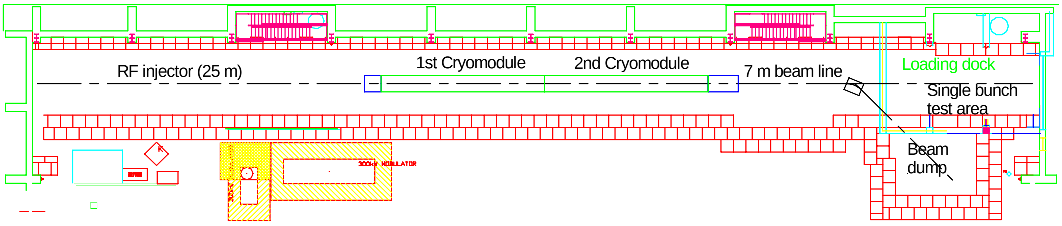


Figure 6.4: The second stage of the NML facility with two cryomodules (summer 2008).

Adding a third cryomodule would require extending the building in order to accommodate the beam dump and the experimental users area. At present, we envision an extension tunnel, which connects NML to a separate building housing the beam dump and an experimental area to be used for AARD (Figure 6.5).

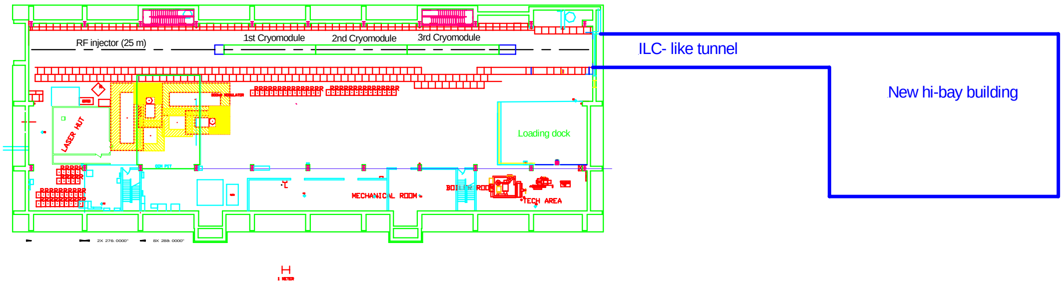


Figure 6.5: A schematic layout for the final stage (FY09 and beyond) of the NML facility.

The building will also house a new cryogenics plan (see next section) needed to operate the facility at the ILC-like conditions. Our plan requires that we start the civil construction on this new building in FY08 in order to be able to install the third cryomodule in FY09. It is planned to construct the new building some distance away from the existing New Muon building in order to allow for the work at NML to continue during the construction. The tunnel extension will connect both buildings and will be constructed when schedule of NML operations allow it. It is planned to make this tunnel of the same cross-section as the ILC tunnel in order to test the installation procedures as well as the waveguide and cable layouts and distributions. The tunnel will be made long enough to allow for a second rf unit, if needed.

In stages 1 and 2 the cryomodules will be powered by a 5-MW Klystron and a bouncer-type modulator. When the 3rd cryomoduled is installed, the rf power will be supplied by an MBK 10-MW Klystron and a Marx-type modulator to be provided by SLAC as part of the collaboration.

The work on the NML accelerator area encompasses several formal and informal collaboration efforts with the following institutions:

DESY (rf power, LLRF, cryomodule design and assembly);
NIU (optics design);
Argonne (controls);
SLAC (rf power, controls, diagnostics, couplers, HOM).

The test beamlines

The test beamlines area will initially contain two beamlines: (1) the dump line and (2) low intensity test line (Figure 6.6). When the ILC rf unit is operated with ILC-like beam parameters and three cryomodules are operational, the beam energy could be as high as 750 MeV and the average beam power close to 40 kW. The TTF at DESY has extensive experience with an electron beam dump for a similar beam energy and power. Our dump design will be closely based on that of TTF. Figure 6.7 shows the approximate layout of beam dumps in the New Muon building.

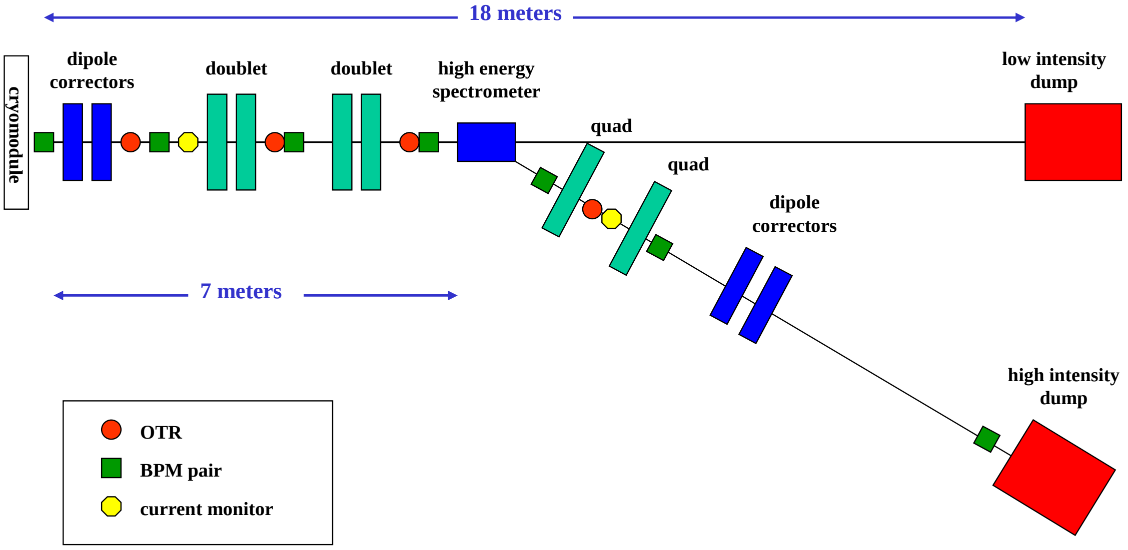
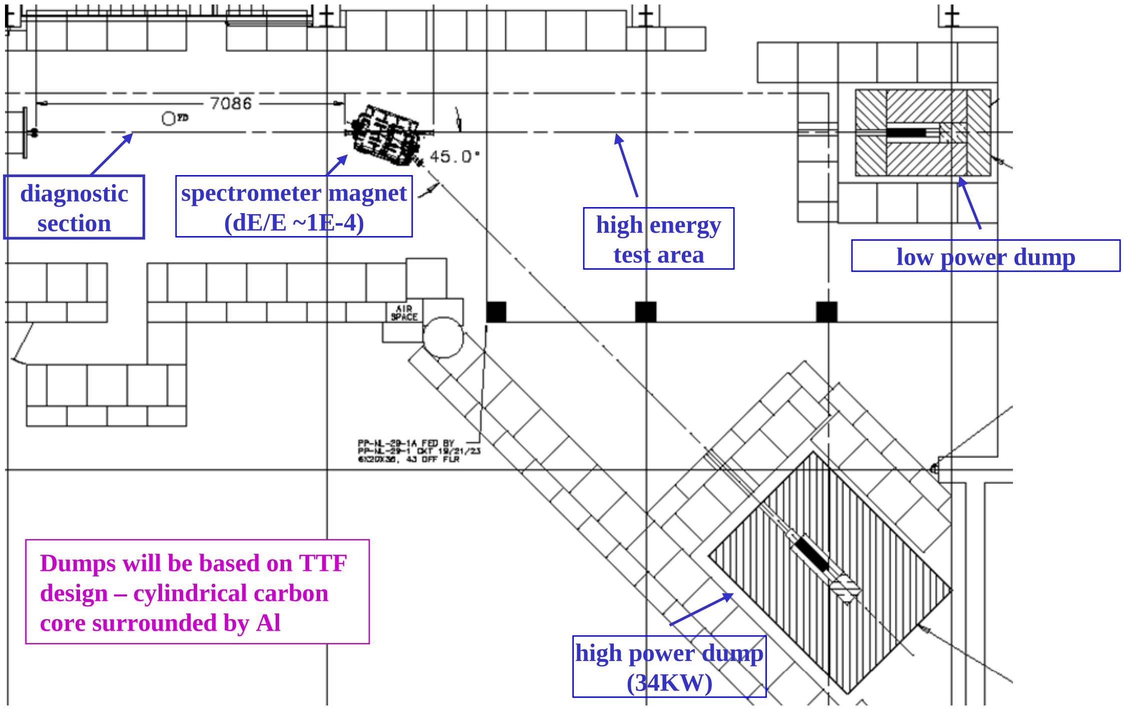


Figure 6.6: The NML test beamlines schematic.



Dumps will be based on TTF design – cylindrical carbon core surrounded by Al

Figure 6.7: The NML test beamlines layout.

Shielding calculations for a 50-kW average power beam at 750 MeV show that the beam dump can be constructed on the building floor using iron plates and concrete shielding blocks. Such a design would allow for an unlimited occupancy outside of the shielded cave with beam on. When the building extension is completed (Fig. 6.5), the beam dumps will be moved to the new building.

The work on the NML accelerator area encompasses several formal and informal collaboration efforts with the following institutions:

DESY (beam dumps, diagnostics);
NIU (beam line optics design, test area design).

A summary cost table appears below. Detailed cost breakdown is provided in a companion spreadsheet to this document.

Cost Summary for ILCTA-NML (in $k)

Expenditure Description	M&S	SWF	Total Including Indirect
NML Conventional Facilities	$ 720.00	$ 445.50	$ 1,462.06
NML Cryogenic System	$ 2,400.00	$ 3,334.50	$ 7,028.21
NML RF Power System	$ 2,900.00	$ 1,849.50	$ 5,953.09
NML Auxillary Systems	$ 530.00	$ 472.50	$ 1,244.66
NML Operations	$ 400.00	$ 1,080.00	$ 1,782.12
NML LLRF	$ 710.00	$ 3,294.00	$ 4,767.47
NML Controls	$ 940.00	$ 4,711.50	$ 6,720.11
NML Instrumentation	$ 1,510.00	$ 2,875.50	$ 5,327.76
NML Injector/Laser	$ 1,230.00	$ 1,323.00	$ 3,152.35
NML Accelerator	$ 250.00	$ 796.50	$ 1,255.37
NML Test Beamlines	$ 990.00	$ 999.00	$ 2,460.54
NML Support Equipment/Systems	$ 2,340.00	$ 1,431.00	$ 4,732.05
NML Building Extension	$ 3,350.00	$ 607.50	$ 5,095.57
Total NML Infrastructure	$ 18,270.00	$ 23,220.00	$ 50,981.35

7. Cryogenic Plant for ILCTA_NM

In this section we have employed the ILC RDR methodology to estimate heat loads and capacity required to support cryomodule testing at the NML. Limited funding has led us to a staged approach for the construction of the NML cryogenic system. For the initial stage, the cryogenics system is based on a single Tevatron satellite refrigerator and a large vacuum pump. This system is currently being installed in the New Muon building.

For the initial stage, the refrigerator, vacuum pump, and a purifier compressor will be located on the east side of the New Muon building. The main helium compressor will be located in a separate existing building situated at ~1100’ to the south of the NML. Both New Muon and the compressor building has additional floor space that can be used to install one more compressor and a second Tevatron satellite refrigerator. Such an addition is planned for the second stage of the NML project. During this second stage, NML will be capable of operating a full RF unit at the 5-Hz repetition rate planned for ILC.

A third planned stage will support operations of the electron photoinjector (PI) and a single RF Unit (three cryomodules) at about 4-Hz repetition rate. The rate achievable will depend on the actual cavity Q-factors achieved and the system static heat leaks. If these loads are higher than expected, we may have to reduce the rep rate even further.

The maximum repetition rate for operation of the PI and up to three cryomodules, which can be supported by the Tevatron satellite-based cryogenics system, is presented in the table below.

NML Stage		**# of Tev Satellite refrigerators**	
		1	**2**
1	PI + Single ILC Cryomodule	1 Hz	5 Hz
2	PI + Two ILC Cryomodules	n/a	5 Hz
3	PI + Single ILC RF Unit	n/a	< 4 Hz

A Tevatron satellite refrigerator-based cryogenics system is expedient and cost effective as a near term solution. It is capable of supporting the 2K refrigeration for cryomodules and allows us to get started quickly. However, the capacity of such a system is quite limited and operation of the cryomodules using ILC thermal shield temperatures and pressures is not possible. In addition, there may be other operational problems for the cryomodules such as the power leads of the ILC quadrupole magnet.

A new higher capacity cryogenic system capable of producing refrigeration at ILC-specific temperature levels will be needed to operate the injector and one or more ILC RF units at the full ILC 5-Hz repetition rate. This proposed system is described below.
The cryogenic plant, liquid storage, and compressor system for the new refrigerator will be located in the new building described in Section 6.5. The new plant will be dedicated to the operation of RF Units at ILC-like parameters and test area, while the two Tevatron satellite refrigerators will provide refrigeration for the photoinjector and crab cavities.

The NML cryogenics system must service an R&D facility that will need to have considerable flexibility for a wide range of loads including full operation at 5 Hz, and turn-down capability for operations with a few modules with static heat load only. We fully understand that this refrigerator is an expensive long lead time item. We will continue to work to examine staging and procurement scenarios. Initially we examined the feasibility of using or modifying existing surplus cryogenic plants, such as more Tevatron satellite refrigerators. We also studies use of a surplus SSC plant for use at NML. The specifics of the ILC operating temperature levels (2.0 K, 5 K, and 40-80 K) would require significant modifications of existing plants. Internal estimates, and those of a paid consulting expert have lead us to the the conclusion that the cost of such modifications would be similar to or perhaps even more expensive than purchasing a new plant designed explicitly for these process streams.

In making the cost estimate below we assumed that the new helium plant should utilize turbo-expanders, oil-flooded screw compressors, and aluminum plate-fin heat exchangers. Pumping to 2 Kelvin may be by means of cold compressors, warm pumping, or a combination. Since this is expected to be staged installation, a pumping system utilizing warm pumping or combined cold and warm pumping will best match increasing cryogenic loads.

Overall plant efficiency is not a primary concern for an R&D facility such as NML. Instead emphasis is placed on flexibility, variable load capability, and reliability in supporting the needs of the test facility. The new cryogenic plant will allow us to operate a string of two RF Units at ILC temperature and pressure conditions.

The costs are summarized in the table below. Detailed breakdown is provided in the Spreadsheet that accompanies this document.

Cost Summary for NML Cryogenics (in $k)

Infrastructure	M&S	SWF	Total with Indirect
Cryogenic Infrastructure	$ 10,690	$ 950	$ 13,690

7. Cryomodule Test System (CTS)

After assembly of a cavity string into a cryostat, the resulting “cryomodule” should be tested on a test stand before incorporation into a string. DESY has recently built such a test stand and we are working closely with them in the design of a similar facility for FNAL. The test stand requires two cryogenic end boxes to provide cryogens and close the two ends of the 12.6 meter long, 1 meter diameter cryostat. All 8 RF cavities would be powered, as well as magnets in the cryomodule. It would be a complete cryomodule test only without any particle beam. The overall accelerating gradient, cavity quality, and input coupler performance could be measured. An important goal of the tests would be to verify the stability of cavity and magnet alignment within the cryostat following assembly, shipping, and cool-down. Within the R&D modules, special instrumentation such as wire position monitors would be used to track individual RF cavity positions and magnet position. Temperature and flow sensors in the end boxes would also allow an assessment of module thermal performance. Cryogenic conditions (temperatures and pressures, although not flows) should be as close to those anticipated within ILC as possible. In particular, helium gas-cooling should be provided for thermal shields rather than liquid nitrogen.

Our current plan for the first few cryomodules is that the NML facility will effectively function as Fermilab’s CM test stand. However, once a full ILC RF unit is installed, it will be very disruptive to use the facility in this way. For this reason we will need to bring a CM test stand on line about 2010 or so. The test stand will need both refrigeration and RF power and must reside in a shielding cave. RF power will be delivered by a 1.3 GHz klystron capable of at least 3 MW driven by a low-level RF system. Klystron choices are under discussion, the only viable candidate at this time is the 5 MW single beam klystron made by Thales. Ion-pump systems will provide the clean vacuum needed for the input couplers, and a turbo-pump system will provide the cryostat insulating vacuum. Data from measurements at the CTS will be logged and entered into a permanent cavity database.

We have not yet determined the best location for the CM test stand. One possibility is the Meson Detector Building. A cryogenic system already exists in the buildings and will only require a new distribution system for first tests of cryogenic modules. However, this current cryogenic system does not provide ILC cryogenic conditions. (It provides LN2 rather than 40-80K helium and 4.5 K helium rather than 5-8 K helium.) In the longer-term, a new cryogenic system is needed for the CM test stand. NML is another possible location under consideration. The issue for NML is floorspace and when the new large cryogenics plant might be available. Finally we note that after the end of Tevatron operations many existing buildings and considerable cryogenics equipment will be available for other purposes. We are studying CM test stands in locations like the CDF building or the IARC building (see below)

The cost summarized below are a “ best guess” of what such a CM test stand might cost and should be thought of as a “place holder” at this point in time.

Cost Summary for CTS (in $k)

Infrastructure	M&S	SWF	Total with Indirect
CTS Infrastructure	$ 5400	$ 2970	$ 10,200

8. SRF material R&D program

In any SRF program, knowledge and material studies are fundamental supports to both production and advanced R&D. The ongoing activities of the SRF material group can be divided in 3 main topics:

- **Support to projects such as QA and failure analysis**. These tasks focus on the characterization of the SC material including: surface state using Eddy Current Scanning, mechanical properties in view of forming and measurement of surface contamination. For instance, recently occurred material ruptures (during forming or cryogenic tests) show us that we need to investigate further the material properties and tighten our specifications.

- **Process R&D**. Surface processing is a key step toward the achievement of high gradients. Within the framework of the ILC program at Fermilab there is a large ongoing effort to develop EP infrastructure in collaboration with several US laboratories. A specific program on sample and small cavities has been established with the goal of understanding and improving the process itself. The program includes Electropolishing, tumbling, dry post-processing such as plasma cleaning and automated cleanroom assembly procedures.

- **Advanced SRF R&D**. Advanced SRF R&D is achieved mainly through collaborations with other institutes and universities that Fermilab has sponsored over the past two years. Fermilab needs to be part of the advanced program in order to benefit from cutting edge knowledge on SC, to keep a scientific leadership in SRF, and to improve projects whenever it is possible (cost, reliability, performance). We are now trying to develop a comprehensive AARD proposal in collaboration with ANL, FSU, MSU, NU… Material and superconductivity experts have gathered around the SRF community. They are trying to understand the origin of the limitations observed in the cavities and to propose new ways to overcome them.

To achieve this mission, specific infrastructures need to be developed:

Single cell test lab: a dedicated RF test stand is mandatory allowing testing 1-cell cavities with a fast turnover. Such test stand is required for the S0 phase of ILC. It would also enable testing specific aspects of the surface processing as well as new material related ideas.

Material Diagnostic lab: it already hosts RRR, Eddy current scanner, SEM, surface profilometer, Tensile tester, ... and must be complemented with additional techniques: mainly SIMS, and cold tensile testing. Surface analysis is a constant issue in SRF where all dissipation sources are arising from the first 50 nm. We need to acquire a sensitive surface analysis tool (SIMS) as well to test the quality of the incoming material, or to perform failure analysis (e.g. broken parts) or to sustain R&D programs. Cold testing will allow us to check material quality, and better estimate the resistance of RF parts during cooldown and RF operation.

Process R&D program can be developed in the existing infrastructures with minor investments, e.g. implementation of 1-cell EP set-up, development of tumbling and dry cleaning set-ups.

SRF R&D: a large program can be conducted with minor investments, provided that we can eventually test new ideas on cavities with the 1-cell RF test stand. The acquisition of a magnetometer could allow us to develop local expertise on the effect of processing on the magnetic (superconducting) properties of Nb.

Cost Summary for Material R&D (in $k)

Infrastructure	M&S	SWF	Total with Indirect
Material R&D	$ 870	$ 722	$1960

9. Illinois Accelerator Research Center (IARC)

Particle accelerators, used in medicine, industry, and physics research, have played a key role in the progress of science and technology in the past and will play an even greater role in the future. The proposed Illinois Accelerator Research Center (IARC) at Fermi National Accelerator Laboratory will provide facilities that serve as a focal point for accelerator research, education and industrialization. IARC will also strengthen the technological and economic health of Illinois while providing unique educational opportunities for a new generation of engineers and scientists.

Description:

A building with 50,000 square feet of usable space and an approximate 300 ft x 100 ft footprint is required. The rear 65 ft of the footprint is high bay heavy assembly area. This area will be equipped with 30 ton overhead crane over an underground enclosure approximately 25 feet below grade. This provides 20,000 square feet of state-of-the-art test space equipped with cryogenics, RF Power, and x-ray radiation shielding for high power testing of superconducting Radio Frequency (SCRF) components, the key technology required to build the ILC. This test area will be the largest and best equipped facility of its type anywhere in the world. The building will use large roll-up doors and a loading area under the crane for the transfer of large equipment. The building will be provided with cryogenic infrastructure, AC power distribution, temperature and humidity control, a low conductivity water system, and connections to existing Fermilab industrial water systems.

The front 35 feet of the building footprint will consist of one floor of light laboratory space (10,000 square feet) at grade level to allow assembly and repair of test devices; and two floors of office space above (about 18,000 square feet) . The building will also contain conference rooms and classrooms equipped with advanced video links essential for international collaboration, and a public display/educational area near the entrance. The building will be sited near the Fermilab Industrial Complex to take advantage of cryogenic refrigeration from the Central Helium Liquefier. It will require approximately 3 MW of installed AC power. The IARC building is estimated to cost $ 35 M with funding to be provided by the State of Illinois. This estimate does not include RF and cryogenic infrastructure which is expected to be provided by DOE. We provide rough estimates for this infrastructure below.

The IARC building will be equipped with RF and cryogenic infrastructure necessary to test cavities and ILC Cryomodules built at Fermilab and in industry at a rate of 2 cryomodules/month. Detailed cost estimates will be prepared that address these requirements. We have set the approximate cost of this infrastructure for the first phase of operation to be that of about 3 CM test stands and 5 VTS systems. This would be matched to the CAF capacity of ~ 2 CM per month. This would require ~ $ 20 M in M&S and about 30 MY of labor but these number should be considered only as educated guesses. We will be working in the next year to flesh out this plan in more detail. It should be noted that the costs to achieve this capability in IARC will be much lower than a facility of this scale built on a green field site because the plan is to leverage existing cryogenic infrastructure (e.g. CHL) after the end of Tevatron Run II. This will also be studied. We currently are commissioning a design study of an “ILC” satellite refrigerator that would use LHe from CHL to provide the required process streams for cryomodules. Similarly, we will study the operational cost and turn down capability of CHL. Construction funds for IARC are in the pending State of Illinois Capital bill. Dependent on when the building is available e anticipate infrastructure funds will be needed in the fiscal years 2009-2011. The testing capacity added by the IARC building should be thought of as the first stage of building the U.S. infrastructure required to test cavities and cryomodules for ILC or as a facility fully capable of testing CM for a project of the scale of HINS. Operated one shift per day 5 days per week it provides 10% of the testing capacity needed by the ILC during peak construction and the testing capacity to build a ILC test linac in two years. With 24/7 operation it could provide about 1/3 of the needed capacity to test ILC cavities and cryomodules at peak production rates. (assuming the U.S. provides 1/3 of the total.)

Cost Summary for IARC (in $k)

Infrastructure	M&S	SWF	Total with Indirect
IARC Infrastructure	$ 20,000	$ 4,050	$ 28,600

8. Summary

Infrastructure	M&S	SWF	Total with Indirect
Total of Cavity Infrastructure	$ 3,000	$ 675	$ 4,375
Cavity Processing Facility	$ 11,100	$ 4,590	$ 15,690
Vertical Test Stand	$ 2,625	$ 1,845	$ 5,590
Total of Horizontal Test Stand	$ 1,220	$ 1,057	$ 2,805
Cavity Dressing and Cryomodule Assembly Infrastruct	$ 690	$ 230	$ 1,160
Cryomodule Test Stand	$ 5,400	$ 2,970	$ 10,200
NML Infrastructure	$ 18,270	$ 23,220	$ 50,980
Total Cryogenics	$ 10,690	$ 945	$ 13,690
Illinois Accelerator Research Center Infrastructure	$ 20,000	$ 4,050	$ 28,600
Material R&D	$ 870	$ 722	$ 1,960
Grand Total	$ 73,865	$ 40,304	$ 134,994

Appendix I

There are many questions to be answered and decisions to be made in this R&D program. The outcomes may substantially influence the desired infrastructure. To provide a flavor for this, and to justify why this is NOT a construction project in the usual DOE sense consider the following issues:

Nb material: qualify companies, determine purities that are acceptable, determine in what form the material is purchased (e.g. Sheets, tubes, or billets) Influences the infrastructure for cutting and inspection

Nb grain structure (fine, large, or single crystal) This will determine the processing used, namely BCP vs EP

Nb sheet fabrication from Billet (rolling vs EDM and diamond saw, or seamless tube)

Cavity formation (deep draw + weld, form tube & hydro form entire cavity)

Weld technique (EBW all, EBW cavity &TIG end groups, TIG all)

Processing technique (BCP, BCP + EP, pure EP, tumble polish then EP, etc)
Process parameters (acid mix, temp, sulfur control, EP voltage & current, etc)

Bake or no-Bake ? (temperature ?)

Finish Process (20 micron EP with fresh acid ? something else ? QC ?)

HPR (water quality, water monitoring, pressure, temp, nozzle pattern, duration, etc.)

Cavity Drying method

Cavity shipping and handling methods

Flange design (DESY, KEK, something else ?)

VTS measurements (High Power processing ? Temperature measurement system ?)

He vessel (Material Ti or SS ? How is it attached?)

Tuner Design (Slow and fast. lever, blade, blade light, electromagnetic, piezo fast tuners)

HTS (yes or no ? If yes, what fraction, what measurements)

Cryomodule (Min changes from TTFIII, design for manufacture, redesign for low cost)

Cryomodule assembly (clean room procedures and infrastructure)

Alignment scheme (DESY vs something better, determines alignment equipment)

Quad (end, center, or separate cryostat) issues are cost, vibration, and cleaning it

Choice of tuner motors and electronics

LLRF design (DESY design, higher IF frequency ?)

Cryomodule test (goals, scope of facility, duration of tests)

ILC RF unit test facility (goals, test program, instrumentation)

ILC test linac (goals, scope, timeline, location, cryo facilities, RF power, etc)

Industrialization plan for cavities and cryomodules

Infrastructure for pre-production test facilities (what is needed? when ?)