ILCTA_IB1 Infrastructure for Vertical RF Cavity Tests

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Acknowledgments

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Introduction

Fermilab is building a Vertical Cavity Test Facility (VCTF) to provide the capability for R&D and pre-production testing of bare ILC multi-cell cavities in the existing Industrial Building 1 (ILCTA_IB1). This building also provides the infrastructure for Fermilab's Magnet Test Facility (MTF), which includes a dedicated 1500W He Refrigerator plant and vacuum pumps for superfluid operation with a capacity of 125 W at 2K. IB1 is a test facility with a long history of successful R&D and production magnet testing, both conventional and superconducting. IB1 staff support is provided by the TD/Test and Instrumentation (T&I) department.

Opportunities created by the expected completion of the production test program for quadrupole magnets of the LHC inner triplet system at the end of CY2006 and by the ramp down of Tevatron magnet testing activities make it possible to expand the scope of the IB1 test area to support testing of bare ILC cavities in VCTF, presently under construction at ILCTA_IB1. By taking advantage of existing IB1 cryoplant and vacuum pump infrastructure, the VCTF can be built quickly and with substantial savings. Operation of the first vertical test stand (VTS) in IB1 is expected to start by mid-CY2007.

This document summarizes the status and expected throughput of the VCTF presently under construction at ILCTA_IB1. This initial VCTF throughput is not expected to be sufficient to support the R&D and pre-production test needs of the ILC program at Fermilab. The ILC R&D Task Force on High Gradients determined that the need of making cavity gradients more reproducible is a top priority ("S0" goal), and in order to accomplish this goal a large number of vertical test cycles would be needed worldwide in the 2007-2009 timeframe. Therefore, this document also presents a plan to increase vertical test throughput by adding two more VTSs and associated IB1 cryogenic system upgrades. This is a follow up to an earlier document [1] where a concept of ILCTA_IB1 infrastructure upgrades to increase VCTF cavity throughput was communicated.

Vertical Cavity Test Facility Construction Status

The primary deliverable for VCTF in FY07 is one complete, commissioned, and operational VTS, capable of testing a single bare 9-cell 1.3 GHz cavity [2]. A cavity test consists of 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]. Although the current IB1 pumping capacity is continuous 125 W at 2K, it has been shown in [6] that this power dissipation can be increased to 250 W for short periods of time without an excessive increase in bath temperature. An ILC baseline cavity is expected to dissipate ~125 W at 35 MV/m. For FY08, we plan to expand the test stand capability to accommodate R&D diagnostic instrumentation, and begin participation in the global GDE/R&D task force S0 tests, both of which require exploring the capability and cavity throughput of VTS, training personnel, and establishing operational procedures in FY07.

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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.

Approximately 4.8 FTEs of effort and $570K of M&S were spent for the VTS project during FY06. The civil construction was completed in August 2006 (see Figure 2), and a cryostat order was placed in September 2006 (see Figure 1). Designs for the RF system and test stand cryogenic system are complete and most items have been purchased. Radiation shielding calculations are complete and the shielding design satisfy the criteria of maintaining "Controlled Area" status in IB1 (i.e., < 5 mrem/hr immediately outside the shielding and < 0.25 mrem/hr in normal working areas). The radiation shield cover (see Figure 3) is under mechanical design. Figure 4 shows a layout of the VCTF, containing one VTS, control racks, and control room.

Remaining major effort includes fabrication and installation of the magnetically-shielded cryostat and top plate, fabrication and installation of the radiation shield cover, installation and commissioning of the test stand cryogenic system, fabrication and commissioning of the RF system, fabrication and installation of a cavity staging area, installation of personnel safety systems, and integrated commissioning. Table 4 in the Cost section shows the cost summary to complete the 1st VTS in FY07. Operation of this facility is expected to start in mid-CY2007.

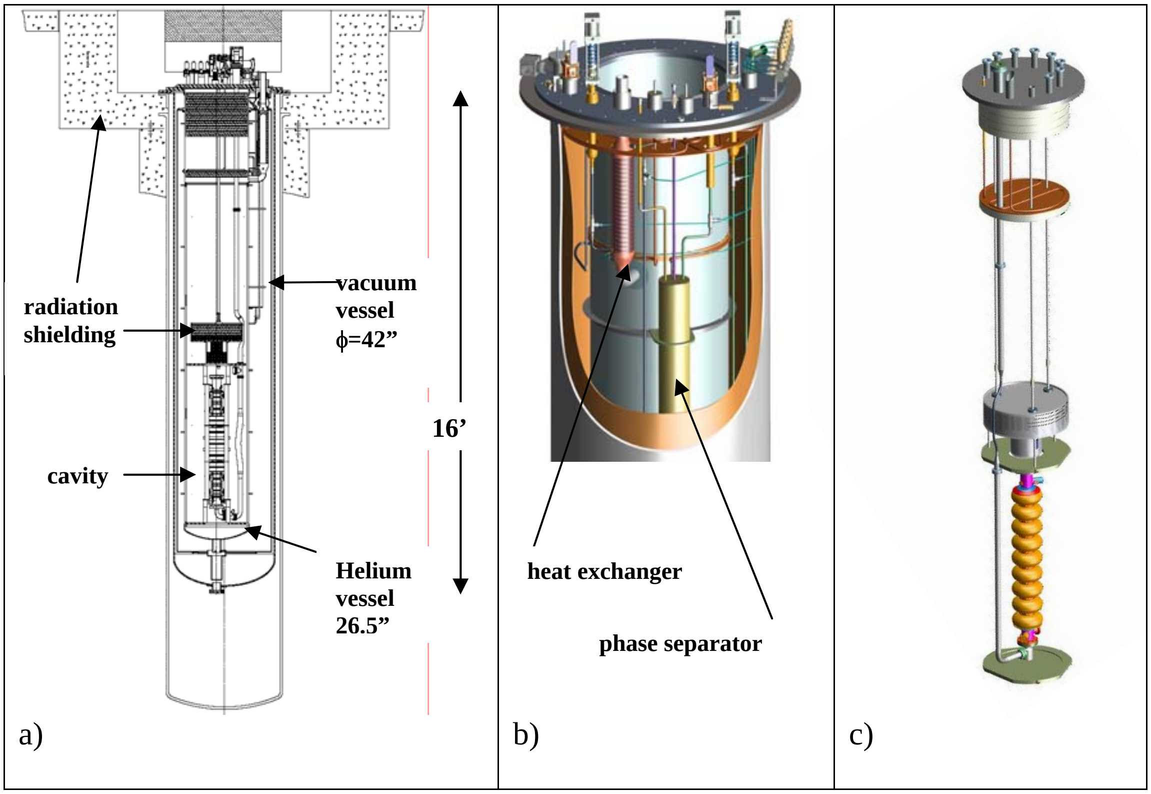


Figure 1: (a) Cryostat design showing vacuum vessel, helium vessel, and a single cavity insert. A portion of the radiation shielding is also shown. (b) Cutaway drawing showing the heat exchanger and phase separator, and (c) Top plate assembly with cavity and radiation shielding insert attached.

Figure 2: VTS civil construction completed in August 2006

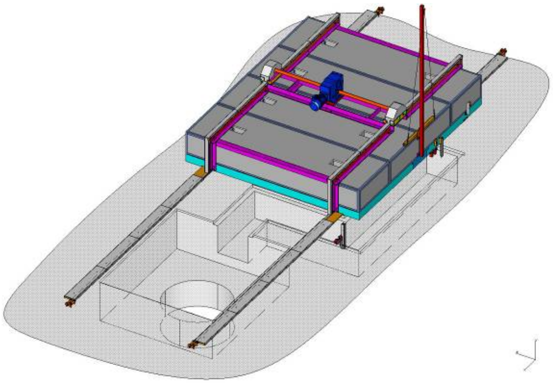


Figure 3: Mechanical design of the radiation shielding lid. The light blue on the bottom is steel, and the gray blocks are concrete with steel frames. The lid is moved over the VTS cryostat for RF testing.

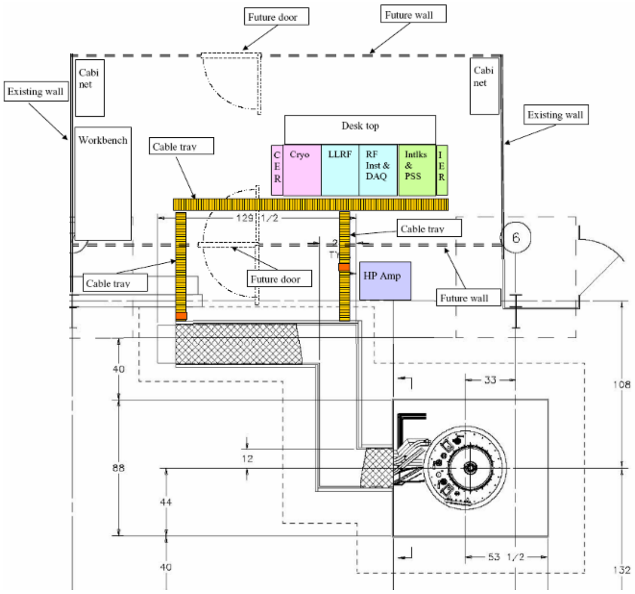


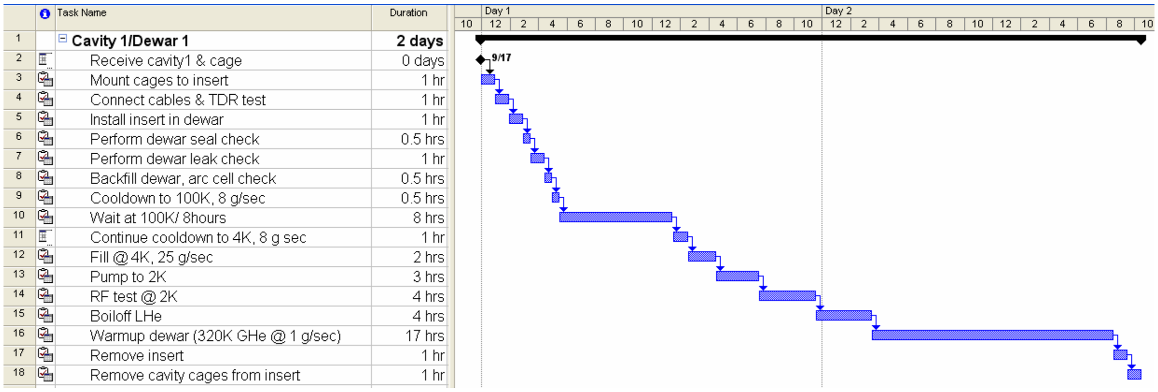
Figure 4: Layout of the VCTF, including one VTS cryostat, instrumentation trench and cable trays, and control room.

Single VTS Test Cycle

The average VTS test cycle duration and number of cycles that the VCTF can support in a year will be first estimated for the case of the single VTS under construction with no other IB1 facility cryogenic infrastructure upgrades or increase in T&I Department current staff level. In addition, the estimate will be for the case when sufficient testing (> 5 to 10 cycles) has taken place to overcome a typical learning curve of operating a new facility and some enhancements have been made to improve the operating efficiency as a result of this learning curve. A complete cavity test cycle includes all the steps from the moment the cavity arrives to IB1 for testing until it leaves the building. A detailed description of each step can be found in [3].

1. Receive cavity and cage
2. Mount cages to insert
3. Connect cables and TDR test
4. Install insert in dewar
5. Perform Dewar seal check
6. Perform Dewar leak check
7. Backfill Dewar, helium contamination check
8. Cooldown @ 4.5K (includes an 8-hr pause at ~ 100K for Q-disease study)
9. Fill @ 4K
10. Pump to 2K
11. RF Test at 2K (for additional details, see [4, 5])
12. Boiloff LHe
13. Warmup Dewar
14. Remove insert
15. Remove cavity cage from insert

Figure 5 shows an ideal schedule to perform these steps. For this schedule, people and equipment are assumed to be available when needed. The total ideal test cycle time is 46.5 hours, with about 11 hours of attended operation and 35.5 hours of nearly unattended operation.



	Task Name	Duration
1	**Cavity 1/Dewar 1**	**2 days**
2	Receive cavity1 & cage	0 days
3	Mount cages to insert	1 hr
4	Connect cables & TDR test	1 hr
5	Install insert in dewar	1 hr
6	Perform dewar seal check	0.5 hrs
7	Perform dewar leak check	1 hr
8	Backfill dewar, arc cell check	0.5 hrs
9	Cooldown to 100K, 8 g/sec	0.5 hrs
10	Wait at 100K/ 8hours	8 hrs
11	Continue cooldown to 4K, 8 g sec	1 hr
12	Fill @ 4K, 25 g/sec	2 hrs
13	Pump to 2K	3 hrs
14	RF test @ 2K	4 hrs
15	Boiloff LHe	4 hrs
16	Warmup dewar (320K GHe @ 1 g/sec)	17 hrs
17	Remove insert	1 hr
18	Remove cavity cages from insert	1 hr

Figure 5: VTS test cycle ideal schedule

In reality, people and equipment are not always available when needed, and some inefficiency such as troubleshooting and repair and facility downtime due to scheduled and unscheduled cryogenic maintenance must be taken into consideration. Following is a detailed analysis of how people and equipment availability will affect the typical duration and frequency of VTS test cycles.

Superconducting Magnet Test Forecast (2007-2009)

Since the VCTF will be integrated with the existing Magnet Test Facility (MTF) at IB1 and will share people and equipment, it is important to understand the expected superconducting magnet test forecast for the next few years.

Historically, the most cryogenically demanding magnet test at MTF has been the 1.9 K testing of a Q2 magnet of the LHC inner triplet system. Q2 consists of more than 11 meters of cold mass (two identical 5.5 m long quadrupoles (MQXB) with a dipole corrector in between), with a maximum stored energy of 3 MJ. About 14,300 liters of LHe are required to cooldown this magnet, and another 1,400 liters are required to recover from a quench. On average, it took about 40 man-weeks to support each production LHC test in FY06. Test Stand 4 has been used for production testing of these magnets. However, this test program is coming to an end with the last Q2 production magnet scheduled to be tested towards the end of CY2006. The next time MTF will possibly see a magnet this large is well outside the 2007-2009 timescale. We may receive a 6-m long LARP prototype magnet to be tested in Stand 4 around 2011-2012.

Superconducting magnet testing in the period 2007-2009 is expected to be dominated by HFM/LARP model magnets, HINS solenoids, and ILC Quadrupoles. Of these, the HFM/LARP model magnets are the most cryogenically demanding and are tested under superfluid conditions (1.9 K). Typical 1-m long model HFM/LARP magnets have a stored energy of 300 kJ and require 4,200 liters of LHe to cooldown and fill, about 120 l/hr to maintain 1.9K conditions and 150 liters to recover from a quench. Occasionally this program will produce 4-m long magnets that need to be tested. These HFM/LARP magnets will be tested in the Vertical Magnet Test Facility (VMTF), and there is a busy schedule associated with the production and testing of several model magnets over the next few years at a rate of about one per month. Testing of these LARP magnets at VMTF represent the major competition for cavity testing activities. It takes approximately 20 man-weeks of dedicated effort to test each HFM/LARP magnet at VMTF.

Table 1 shows a summary of the information presented above, including VTS projections for comparison.

Table 1: Comparison of LHe consumption requirements and test schedule for IB1 superfluid test objects

Superfluid Test Object	Maximum Stored Energy	LHE consumption (liters)	Test Schedule
LHC Production Quadrupole	3 MJ	14,300 l + 1,400 l/quench + 120 l/hr @ 1.9K	Last test: Jan. 2007
HFM/LARP R&D Magnet (1-m)	300 KJ	4,200 l + 50 l/quench + 120 l/hr @ 1.9 K	~ 12 tests/year
VTS	-	2,000 l + 50 l/hr @ 2K + 173 l/hr @ 125 W	Start mid-2007

IB1 LHe Refrigerator Availability

The IB1 LHe refrigerator availability is limited by the following planned and unplanned shutdown events: (1) Scheduled Maintenance; (2) Contamination Problems; (3) Electrical Problems; (4) Mechanical Problems; (5) Fermi Site Problems; and (6) Other Problems. Figure 2 shows for the past three years the number of days the IB1 LHe refrigerator was not available due to each event. From this figure, the IB1 refrigerator was unavailable on average 45 days per year (88% availability).

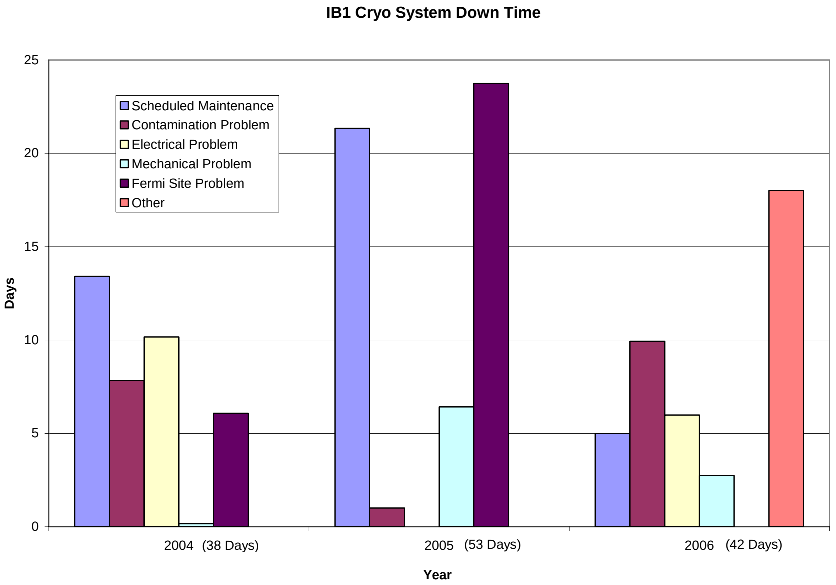


Figure 6: IB1 LHe Refrigerator downtime

Of these downtime causes, the one with the most risk of increasing by adding more sub atmospheric test stands like the VTS is contamination problems. Contaminations such as nitrogen and oxygen are introduced in the IB1 refrigerator in several ways, but air leaks into sub atmospheric volumes are a major concern. Air leaks can be through o-rings and seals, and it is not possible to completely ensure an air-tight system. Once contamination is present in the IB1 cryogenic system, it will migrate to the cold box and freeze at various locations reducing the efficiency of the machine and eventually forcing a shutdown to warmup and purge the system from this contamination. Efficiency is reduced in several ways by contamination, for instance by plating heat exchangers, clogging pipes, and clogging filters. Contamination has been the cause of turbine damage in the IB1 cold box, and in extreme cases contamination could cause a catastrophic failure of a heat exchanger (contamination expands when freezing) which would require a very long IB1 cryogenic system downtime to repair (at least several months). The reason why contamination is such a concern in the IB1 refrigerator is because, unlike modern helium refrigerators, the IB1 system does not have a full-flow dual-bed purifier between the compressor plant and the cold box. All other high-throughput SRF cavity test systems (e.g., Jlab and DESY) have a full flow purifier in their cryogenic system. A full-flow purifier eliminates any contamination from the system before starting the cooldown inside the cold box. The IB1 cryogenic system only has a partial flow purifier, which can take and purify just 10%-20% of the 200 g/s flow between the compressor plant and the cold box, leaving the rest of the contamination to freeze and deposit into the cold box.

Over the years, IB1 cryogenic engineers and operators have learned to deal with contamination and mitigate its associated risks, but as can be seen from Figure 6 it is not possible to completely eliminate shutdowns associated with it. Examples of how operators deal with contamination are several, here is just a sample:

- At every planned maintenance shutdown, the entire oil inventory of the compressor plant is processed to eliminate any trapped water vapor and air resulting from air leaks. Trapped water vapor and air in the oil has been found to slowly migrate to the cold box and has been one of the main causes of expensive turbine damage. The oil is processed in a special AD facility, and it takes about a week to process the whole oil inventory.
- Whenever there is a refrigerator shutdown for causes other than contamination, if the plant is down for more than a few hours then the entire coldbox is warmed up and scrubbed. This is a precaution to prevent frozen contamination from being released during a partial warmup and then frozen again further downstream and in more critical areas when the plant is restarted. This procedure adds approximately 5 to 6 days to a non-contamination related shutdown.
- For the first hour after pumping starts in a subatmospheric test stand, the helium is vented to atmosphere rather than returned back to helium compressor suction. The assumption is the test stand is contaminated because of air leaks or contaminants that cannot be removed during the pump and purge procedure. According to our operation procedures, each cryogenic test stand needs to be pumped and purged 5 times before cool down start.

The risk of contamination will only increase by adding more sub atmospheric test stands like the VTS. The risk scales with number and length of seals, number of sealing operations, and duration of sub atmospheric operation. Although it is hard to quantify this risk, it is certainly a cause for concern. We estimate an additional 15 days of unplanned downtime per VTS associated with the increased risk of contamination. However, the risk could be a lot higher. One way to handle the risk is by venting helium rather that returning it to gas storage. This is a wasteful alternative for a non-renewable resource, but also expensive: Fermilab pays $2.66 per liter He equivalent of GHe (1 liter of LHe equals 125 grams), and assuming that venting takes place at the Kinney pump existing capacity of 6 g/s then the cost of venting He is approximately $460/hr.

Therefore, the total IB1 cryo system downtime with one VTS is estimated to be on average 60 days per year (84% availability).

Vacuum Pump Availability

There are two vacuum pumps at IB1 for superfluid operation: Kinney Pump I (4 g/s) and Kinney Pump II (2 g/s). These pumps are used together to provide 6 g/s of pumping capacity, equivalent to 125 W at 2K [6].
In the current VTS design configuration, these vacuum pumps are shared with the Magnet Test Facility (MTF). It is not possible to simultaneously pump on both the VTS and a superfluid magnet test stand. Therefore, there will be instances when the VTS

needs to wait for the vacuum pumps to become available from superfluid magnet testing. Using the FY07 superfluid testing schedule as a guideline, we expect approximately 12 HFM/LARP superfluid magnet tests at the VMTF test stand per year. Each test will occupy the vacuum pumps for an average of 3 days, resulting on a total of 36 days in a year of vacuum pumps supporting non-VTS operations and unavailable to support VTS operations. It is hard to estimate how often this interference will occur and for how long. However, it is important to note that pumping usually takes place during the single shift operation so VTS testing will be inefficient on weeks when VMTF magnet testing is going on. We will assume that on average we need to wait for vacuum pumps for 2 days when VMTF testing is taking place, for a total of 24 wait days in a year. This number may increase in future years if superfluid operation is also required for other magnet test programs such as the ILC quadrupole.

Liquid Helium Inventory Availability

The VTS requires approximately 2,000 liters of LHe to cooldown and fill. The amount of LHe inventory that the VTS will hold is about 1,000 liters. With the IB1 refrigerator working at nominal efficiency, we can conservatively expect a LHe make rate of 250 l/hr [7]. Assuming a VTS test cycle takes 5 days (see Table 2), then on average the VTS will require only 17 l/hr. This is a small fraction (7%) of the liquefaction capacity of the IB1 cryo plant. However, this is the average LHe consumption. Peak LHe consumption could be much higher if there is simultaneous magnet quenching and VTS filling going on. The IB1 cryo system can deliver LHe to a test stand from the LHe storage dewar at a rate nearly 3 times higher than the LHe make rate (700 l/hr). The ability to meet peak demands depends on the amount of LHe storage, and there is a possibility that the LHe inventory required to support a VTS test cycle will not be available when needed because LHe inventory storage has been depleted as a result of a prior magnet test. It would take 8 hours (an entire shift) to accumulate enough LHe inventory to support a VTS test cycle. A contingency for LHe delivery to a VTS could be provided by portable LHe dewars. At a cost of $1,200 per 500 liter dewar, it would cost approximately $6,000 to support a test cycle. The VTS is being designed with the ability to accept LHe supply from portable dewars.

The IB1 cryogenic system has a 10,000 liter LHe storage dewar which can store approximately 7,000 liters of LHe (some gas space is needed in the dewar for adequate pressure control). However, gas storage capacity is limited to the equivalent of 3,900 liters of LHe. Gas storage is provided by three 30,000 gallon tanks, and their pressure must be maintained between a minimum of 50 psia and a maximum of 180 psia.

Accumulating more LHe than the GHe storage capacity would result in either venting the excess to air at some point (a wasteful and expensive mode of operation), or stopping test operations to make liquid and reduce the gas storage tank pressure. Given the relatively small amount of LHe inventory buffer, we estimate that every time there is a VMTF magnet test the entire LHe inventory is depleted so it takes an extra day of waiting for the IB1 cryogenic system to make enough liquid to support VTS operations. This adds to about 12 additional wait days in a year.

Vertical Cavity Test Facility Availability

In addition to the availability of systems to support VCTF operations, the availability of the VCTF itself must be taken into account. There will be instances when the VCTF equipment breaks down and some time will be spent troubleshooting and repairing the problem. Contamination is again an important source of sub atmospheric test stand down time, and sometimes a thermal cycle is required to eliminate the problem. There is no historical information yet on which to base an estimate of the VCTF availability, but from our experience with other IB1 test stands, we estimate an additional 15 days in a year of VCTF downtime.

People Availability

The IB1 test facility currently operates in a single-shift mode, with the exception of two-shift coverage for cryogenic operations which includes weekends. With this facility staffing arrangement, attended VCTF operations must be conducted within the single-shift coverage, sharing people with other test activities. The lean IB1 technician staff makes this single-shift work inefficient due to interferences such as conflicts with other work, meetings, vacation, sick time, and so on. Nearly unattended VCTF operations still require occasional actions initiated by cryogenic operators. Because of the two-shift coverage for cryogenic operations, there will be instances when actions cannot be initiated because there is nobody there, and there will be a wait time until the next cryo operator shift arrives. In addition, during shift coverage operators are also busy controlling and monitoring other test stands so there will be times when delays will be incurred because of this fact.

Because of the waiting time for people to be available to work on VCTF operations, we estimate that the ideal 46.5 hour test cycle (almost 2 days) is stretched to ~ 5 days. Of course having a dedicated crew to work on VCTF operations and allowing multiple shift operations can have a substantial impact on reducing the test cycle time. In addition, people are not available to work on VCTF during holidays (10 days in a year).

Expected Number of Test Cycles in a Year without Upgrades

Table 2 shows the expected number of test cycles annually for a single VTS in the VCTF with the assumptions given above.

Table 2: Expected maximum number of VTS test cycles in a year without any upgrades

IB1 Cryogenic System Downtime	60	days
IB1 Vacuum Pumps Unavailable	24	days
LHe Inventory Unavailable	12	days
VCTF Unavailable	15	days
TOTAL EQUIPMENT UNAVAILABILITY	111	days
HOLIDAYS	10	days
VTS Test Cycle (incl. shift operations)	5	days
Number of Test Cycles in a Year	**48**	

Therefore, a typical VTS test cycle with the current IB1 infrastructure and support staff is expected to take on average 5 days, and no more than ~ 48 test cycles can be supported in a year.

IB1 Infrastructure Upgrades to Increase VCTF throughput

The initial VCTF throughput of 48 cavity tests in a year 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 cavity throughput. This plan is a follow-up to an upgrade concept presented earlier [1].

Upgrade VTS for two cavity operation

Adding a second cavity into the test cryostat is expected to be the single most effective way of increasing the test stand throughput.

Although the VTS will be commissioned and initially operated with one 9-cell 1.3 GHz cavity, the cryostat was designed to have sufficient space to accommodate two 9-cell 1.3 GHz cavities. Each cavity will be RF tested individually. Because the RF portion of a cavity test takes less than 10% of the total test cycle duration (see Figure 1), substantial time can be saved by cooling down and warming up both cavities together.

Upgrading the single VTS for two-cavity operation can have a substantial impact on throughput with a relatively modest investment. With all other factors remaining the same, we estimate that the 5-day VTS test cycle is extended to 6 days by adding a second cavity because of the additional RF test time and cavity handling time. With only one additional day in the VTS test cycle, we can now test two cavities instead of one.

Significant effort has been made to accommodate a two-cavity configuration in VTS-1, in all aspects which do not negatively impact the VTS-1 completion schedule. The test cryostat has been designed to fit two cavities end-to-end. In the two-cavity configuration, each cavity would have separate connections to the top plate for RF and vacuum. The existing top plate design has provisions to accommodate these extra connections. Radiation shielding calculations are currently being performed to determine whether the existing shielding design is adequate for the two-cavity configuration, or how the shielding can be minimally upgraded. Because this is a complicated analysis, it will not be completed in time for the VTS radiation shielding procurement.

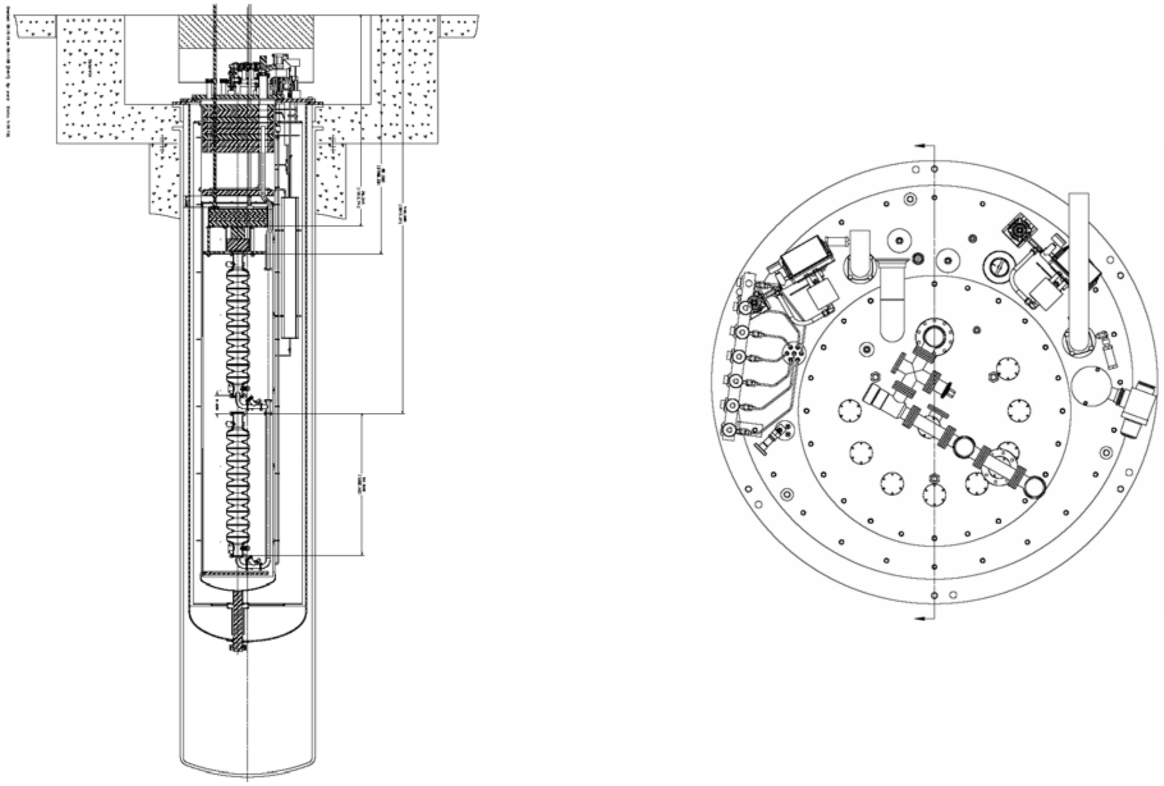


Figure 7: VTS pit and cryostat cross-section showing a possible two-cavity configuration (left) and top plate (right).

A typical two-cavity VTS test cycle with the current IB1 infrastructure and support staff is expected to take on average 6 days. From Table 2, no more than ~ 80 test cycles can be supported in a year. Two-cavity operation increases the VTS throughput by 67%.

Add two more two-cavity vertical test stands

Additional throughput increase can be achieved by additional VTS systems. An analysis of the IB1 space shows that two more identical vertical test stands with the associated staging area can be added. Figure 8 shows a layout for the additional VTSs and staging area, Figure 9 shows the IB1 building area proposed for this upgrade, and Figure 10 shows a 3-D conceptual model of this layout.

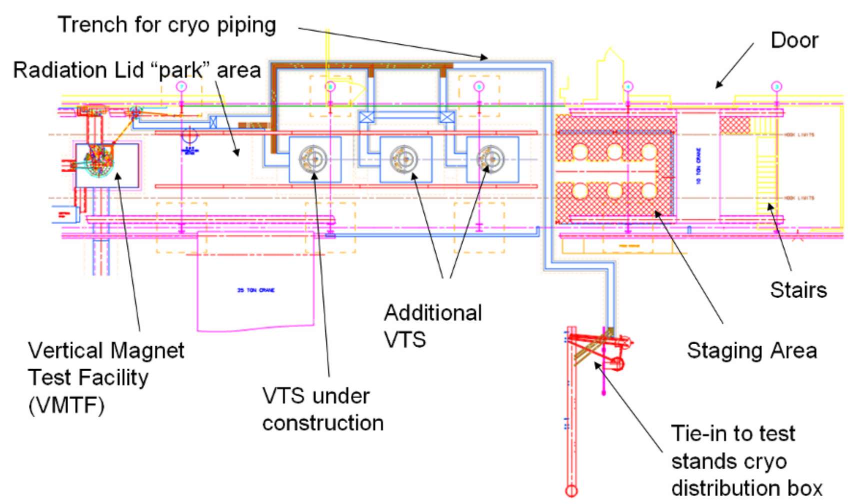


Figure 8: Conceptual layout of VCTF, including staging area, instrumentation trenches and cable trays for three vertical test stands.

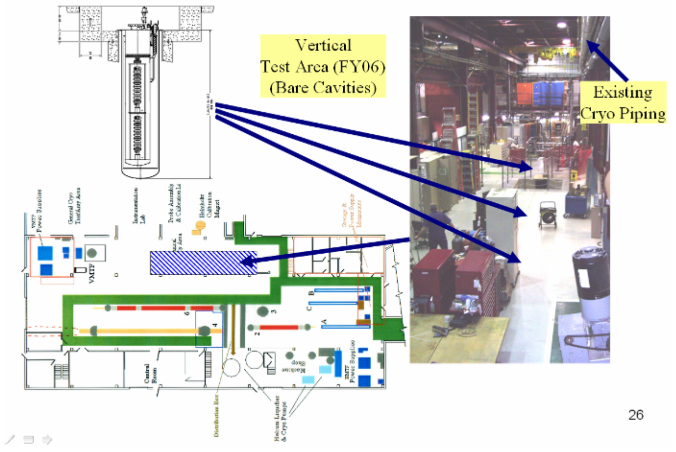
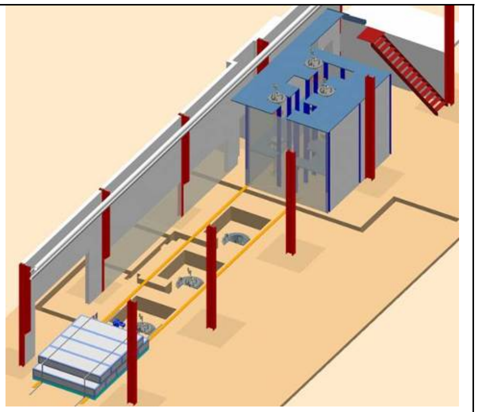
	

Figure 9: Proposed location of the additional vertical test cryostats in the IB1 building	**Figure 10: Conceptual design of two additional vertical test cryostats (foreground) and a top plate assembly staging area.**

In this model, RF testing can occur in only one VTS at a time. As mentioned previously, this is not a big constraint because RF testing is only 10% of the total VTS test cycle. The same radiation lid is shared among all VTS stands as shown in Figure 10. The same RF and DAQ system (with the exception of the power amplifier) is multiplexed among all three VTS stands. This is the mode of operation at other labs with multiple production test stands. The power amplifier is not multiplexed, because it has to be in close proximity to the VTS top plate to avoid excessive losses.

The staging area is large enough to have provisions for up to six top plates (two for each VTS), so the next two-cavity insert can be prepared while the previous one is still undergoing a test cycle. It is also high enough to accommodate a two-cavity insert.

In a multiple VTS scenario, we propose to change the way how LHe is supplied and returned to each VTS to minimize losses and increase the liquefaction efficiency. Figure 8 shows that a trench is included to connect the VTS cryostats to the IB1 test stand distribution box. This allows LHe to be supplied with less loss, and returning the VTS He inventory as cold gas through the cold box. This arrangement will improve the LHe availability for cavity testing and magnet testing.

To minimize design SWF cost, we propose to add two more nearly identical vertical test stands. However, it is important to understand that the existing cryostat design is limited to about 8 to 10 g/s (160 to 200 Watts) of continuous 2K operation due to excessive JT Heat Exchanger shell side pressure drop. This is independent of the vacuum pump capacity. Figure 11 shows the location of the cryostat JT Heat Exchanger and its pressure drop as a function of flow.

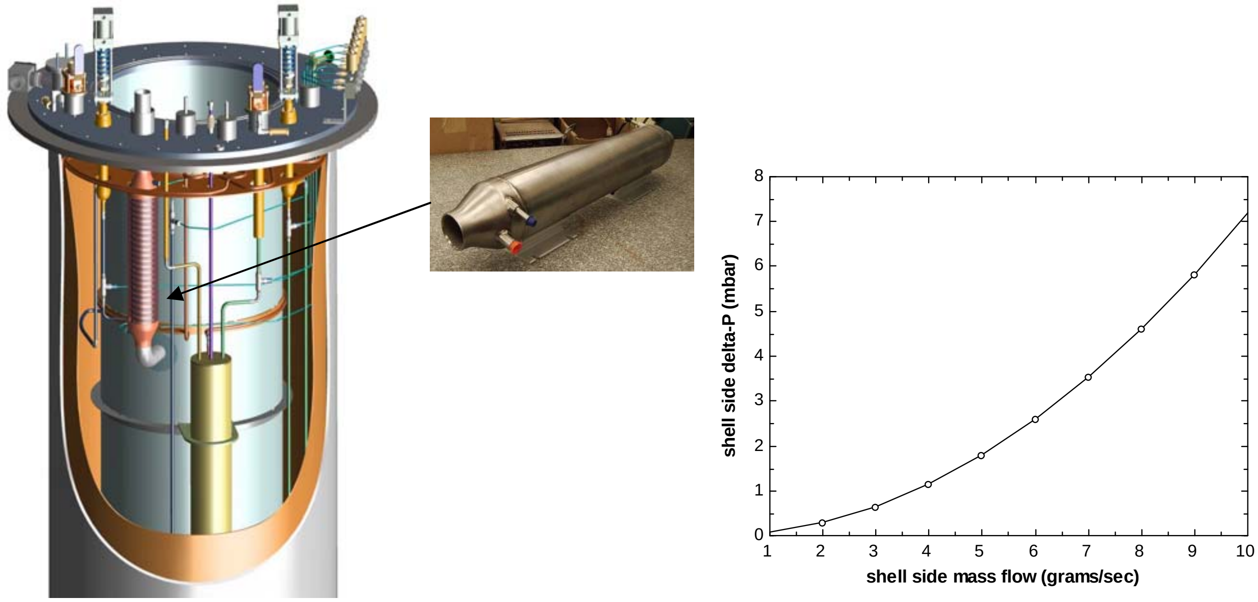


Figure 11: JT Heat Exchanger location and shell side pressure drop as a function of flow

For a baseline ILC cavity (E = 35 MV/m, Q = 10^{10}), the power dissipation is:

$$P = \frac{E^2 l}{(r/Q)Q_0} = \frac{(35x10^6 V/m)^2 1.038m}{(998\Omega/m)1x10^{10}} = 127W$$

This is equivalent to 6 g/s at 2K of pumping. Substantial margin is needed to continuously operate at higher gradients and/or lower Q.

It is therefore very important to understand if there will be a future need to remove more than 200 Watts (10 g/s pumping) before duplicating the existing design. If additional margin is desired, a higher capacity JT heat exchanger must be used in future VTSs. A proven higher capacity heat exchanger design is available, but its integration into new VTSs may require an adjustment to the cryostat (and pit) diameters.

Based on the existing VTS civil construction, we estimate that the addition of two more pits will require a 6-week long shutdown of the IB1 test facility. It will be beneficial to schedule this civil construction together with other planned extended test facility shutdown to minimize the impact to magnet test programs.

Adding two more VTS systems without upgrading the IB1 cryogenic infrastructure or increasing the IB1 support staff will substantially limit the potential throughput increase. Examples of these limitations are an excessive risk of contamination-related downtime and excessive cryogenic coupling with the Magnet Test Facility through sharing equipment such as vacuum pumps for superfluid operation. Following are upgrade recommendations to eliminate these bottlenecks.

IB1 Cryogenic Infrastructure Upgrade

Figure 12 shows a highly simplified block diagram for integrating the single VTS system presently under construction into the IB1 infrastructure.

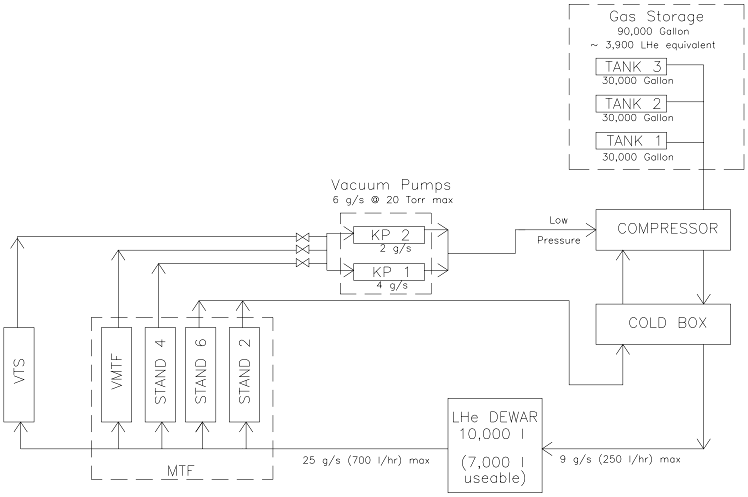


Figure 12: Single VTS integration into IB1 infrastructure

Figure 13 shows a block diagram for a 3-VTS system plus IB1 cryo infrastructure upgrades.

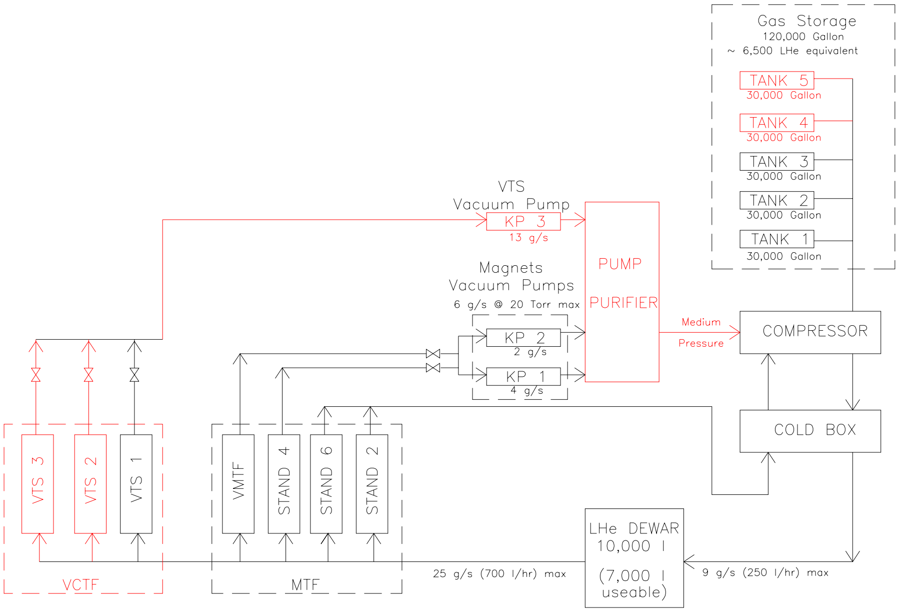


Figure 13: 3-VTS integration into IB1 infrastructure plus cryogenic upgrades

Following is a detailed description for each upgrade proposed.

Add a Compressor/Purifier Skid

As mentioned previously, the risk of contamination increases by the addition of a sub atmospheric test stand because unlike the Jlab or DESY systems, the IB1 cryogenic system does not have a full flow purifier that removes He contaminants prior to cold box cooling. Contamination-related downtime of the IB1 cryogenic system is now responsible for at least 10 days in a year, certainly more if we take into account long thermal cycles performed on the refrigeration system to avoid contamination problems. We estimated that each VTS will increase this downtime by at least another 15 days, although the risk is hard to quantify and could be longer. The risk of operating without an adequate purifier is quite large. For example, a small operator error could very quickly increase system downtime by a week or more (the time that it takes to warmup and scrub the cold box).

Understanding that the cost of a full flow (200 g/s) purifier may be too high, we propose to install a compressor/purifier skid at the outlet of the vacuum pumps (~ 30 g/s) 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. The system we propose for IB1 is similar to the one recently installed at ILCTA_MDB. Figure 14 shows a picture of this system.

ILCTA_MDB Compressor Skid for Purifier	ILCTA_MDB Purifier

Figure 14: ILCTA_MDB Compressor/Purifier System

Add a dedicated large vacuum pump

The next recommendation to increase throughput is to install a dedicated vacuum pump for the 3-VTS facility. Sharing the existing magnet pumping system creates a strong coupling between VCTF testing and HFM/LARP magnet testing. This coupling is expected to reduce throughput and generate frustration for both test programs. Moreover, the existing pumping capacity (6 g/s or 125 W at 2K), is just enough to support continuous 2K operation of a baseline ILC cavity. Additional margin for testing cavities with higher gradients and/or lower Q's, or processing field emitters, is highly desirable. We propose to install a pump similar to the one installed at ILCTA_MDB (at least 10 g/s of dedicated pumping capacity). Figure 15 shows a picture of the ILCTA_MDB Kinney pump.

Figure 15: ILCTA_MDB Kinney Pump

With a dedicated vacuum pump for VCTF, superfluid magnet testing can proceed in parallel with cavity testing.

Add two more 30,000 Gallon GHe storage tanks

The helium gas storage capacity of the IB1 cryogenic system is limited to approximately 55% of the maximum LHe storage capacity. Experience from more than 20 years of operation has shown that this is a limiting factor in cryogenic test operations at IB1. 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 in order to re-liquefy helium and lower the buffer tank pressure. The addition of two (2) more 30,000 gallon buffer tanks will increase gas storage volume and would allow the cryogenic system to support longer periods of testing. Figure 16 shows an example of an existing 30,000 gallon IB1 buffer tank. Two additional tanks can easily be accommodated next to the tank shown in this figure.

Figure 16: Example of a 30,000 gallon GHe storage tank

IB1 Power Feed Upgrade

The IB1 cryogenic upgrades will require approximately 350 HP (276 kW) of additional power for motors. Power for motors is supplied to IB1 via transformer YIB1-A, which is running close to full load with only 30 kVA margin. The other two IB1 transformers (YIB1-1 and YIB1-2) are used for instrumentation power, and the recommendation has been to not use power from these transformers to run motors. The preferred option would be to add another transformer to increase IB1 power availability for motors.

We have asked FESS to provide us with a budgetary estimate by January 12, 2006 for the addition of a 1,500 KVA transformer to expand the power availability for motors. Meanwhile, we are using a preliminary rough estimate provided by FESS for this document. More studies will be needed to determine the best course of action to supply the extra motor power require by the cryogenic upgrade.

IB1A Small Building Addition

The new cryogenic equipment (Compressor/Purifier skid and Kinney Pump) will require an addition to the IB1A building. There is no room for this equipment in either IB1 or IB1A buildings. Figure 17 shows a preliminary location for this addition. The final location, size, and cost for this building need to be worked out. We have provided a rough estimate for its cost.

Figure 17: Preliminary building location for additional IB1 cryogenic equipment

Add a Crane

In order to have the flexibility to simultaneously perform work that requires the use of a crane at both the VMTF and the VCTF, we propose that an additional 10 ton crane be installed. The plan is to have the crane beam ride on the same rails with stops that limit their respective range of travel to a dedicated test facility (VMTF or VCTF). Fermilab's Facilities Engineering Services Section (FESS) is studying the feasibility of such a solution, and will provide cost information.

Add Staff

With the addition of two more vertical test stands, staff should be added as well to properly support a 3-VTS continuous operation. It will be no longer possible to share technicians with other magnet test stands without significant delays. For throughput estimation of a 3-VTS facility we assume that enough staff is available to support its operation, at least at the same level of support than a 1-VTS operation. With this assumption, the duration of a double-cavity test cycle on a 3-VTS facility is assumed to be 7 days, allocating one additional day with respect to the 1-VTS test cycle to account for interferences among VTS operations (e.g., wait for another VTS to finish RF testing, wait for another VTS to finish pumping, etc). Interferences can be minimized by process automation and scheduling optimization.

Projected Throughput Increase Summary

An attempt was made to estimate throughput gains for various combinations of the upgrades presented in this document. Table 3 shows the results. Upper limits for the number of tests in this table are highly dependent on the duration of a VTS cycle. For example, in the case of 3 VTSs and 2 cavities per VTS (last column), eliminating the 8-hour wait at 100K and performing only a Q vs E measurement could reduce the cycle duration by one day (from 6 to 5). This would yield 318 cavity tests in a year. Adding a second shift can also result in a significantly higher throughput.

Table 3: Estimates of number of cavity test cycles in a year for each upgrade scenario based on expected downtime causes. All numbers are given in days.

Scenario	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**[a]	**73**	**118**	**264**

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

Following is a brief explanation for deviations in the numbers with respect to the baseline case (first column in Table 3, copied from Table 2).

Cryo down: we estimated that contamination-related problems add 15 days of downtime for each VTS. Therefore, two more VTSs without a cryo upgrade will add 30 days of downtime (total of 90 days) and with cryo upgrades there is no additional downtime due to VTS-related contamination (total downtime same as now, ~ 45 days from the average of Figure 1)

Pumps unavailable: this refers to vacuum pumps being busy supporting other operations (either magnet testing or another VTS). Without a dedicated pump for VTS, we estimated that adding two VTSs will increase the interference and add 12 days of downtime (total of 36 days). With a dedicated pump for VTS, we estimated 0 days of downtime for one VTS (pump is there to support the single VTS and nothing else), and 10 days of downtime for the case of 3 VTS (sometimes the pump will be busy supporting other VTS test cycles).

LHe supply out: this refers to lack of LHe to support a VTS test cycle, either because the LHe storage run out of LHe, or because the GHe storage tanks have reached their maximum pressure and testing must stop to liquefy He and reduce this pressure. Three

VTS cryostats will increase the demand for LHe, so we estimate 8 additional days of downtime because of this increased demand without the addition of GHe storage tanks. With the addition of GHe storage tanks, we estimate no LHe availability related downtime for one VTS, but for 3 VTS we estimate about 10 days of downtime.

VTS Unavailable: Since there are several systems that are common to all three VTS (e.g., RF and DAQ system, valves, etc) the test stand related downtime is not expected to increase linearly with the number of test stands. We estimate an additional 10 days for a 3-VTS system.

VTS test cycle: adding another cavity to a cryostat is expected to increase the test cycle by one day because of the additional handling and RF test time. Adding staff is expected to decrease the test cycle by one day because people will be available more often when needed. Adding two more VTSs is expected to increase the test cycle of each VTS by one day because of interferences (e.g., it is not possible to perform RF testing simultaneously on two VTSs, or pump down simultaneously).

Cost

Cost estimates for VCTF M&S and SWF are presented in the following tables. In all cases we assumed the SWF cost per FTE is 135 $k, M&S overhead is 0.3098, and SWF overhead is 0.1650.

Table 4 is a summary table for FY07 M&S and SWF cost estimate to complete both VTS-1 minimum goals and proposed FY07 VTS-1 upgrades such as variable coupler and thermometry as defined in [2]. A detailed bottom up FY07 cost estimate supporting this summary information was submitted to ILC Program Management on 12/4/06. Some of the FY07 cost associated with upgrades (~108K M&S and ~3.2 FTEs) may transfer over FY08 if funding and/or sufficient resources are not available to complete these tasks in FY07.

Table 4: Summary of M&S and SWF to Complete VTS-1 (FY07 goals)

Infrastructure	M&S ($k)	SWF (FTEs)	SWF ($k)	Total with Indirect ($k)
VTS-1 (FY07 to complete)	651	13.1	1768.5	2913

Table 5 is a summary table for VCTF M&S and SWF cost estimates for FY08 and beyond, which includes upgrades such as two additional VTSs plus cryogenic infrastructure intended to increase VCTF test throughput.

Table: 5 Summary of M&S and SWF for VCTF Infrastructure upgrades (FY08 and beyond)

Infrastructure	M&S ($k)	SWF (FTEs)	SWF ($k)	Total with Indirect ($k)
VTS-1 (w/ 2 cavities)	75	1	135	255.5
VTS-2 and -3	1300	6.67	900.45	2752
Cryogenic system upgrade	1251	6	810	2582

Table 6 is a more detailed breakdown of the M&S cost shown in Table 5.

Table 6: M&S details for VCTF Infrastructure Upgrades (FY08 and beyond)

System	Item	Unit Price	Price Source	Qty	Total M&S
Infrastructure Upgrade					**$1,250,312**
	Vacuum Pump Skid				
	~ 10 grams/sec Kinney Pump	$245,000	Vendor Quote	1	$245,000
	Isolation Valves	$8,000	Vendor Quote	4	$32,000
	Piping, Flanges, etc.	$12,000	Vendor Quote	1	$12,000
	Controls	$80,000	Estimate	1	$80,000
	Purification				
	High Pressure Compressor	$90,000	AD Cryo (for 0.5 Micom)	1	$90,000
	LN2 HX	$74,012	AD Cryo	1	$74,012
	Dual Charcoal Beds	$52,300	AD Cryo	1	$52,300
	Helium Gas Storage				
	Buffer Tanks	$60,000	Vendor Quote	2	$120,000
	IB1-A Building Modifications				
	Civil Construction	$200,000	Estimate	1	$200,000
	10 Ton Crane (incl. Installation)	$45,000	($38K for exist. VMTF in 19	1	$45,000
	Power System Upgrade	$300,000	Estimate	1	$300,000
Additional VTS (2)					**$1,299,457**
	Civil				
	Pit/shafts	$100,000	FESS (VTS-1)	2	$200,000
	Trenches	$80,000	Estimate	1	$80,000
	Fiberglass Liner	$12,000	VTS-1	2	$24,000
	VTS				
	Cryostats	$145,000	Vendor Quote	2	$290,000
	Code Certified Top Plate assemblies (incl. baffles a	$20,000	Estimate	6	$120,000
	Internal and External Magnetic Shielding	$52,586	Vendor Quote	2	$105,172
	Internal Radiation Shielding (lead and polyethylene	$4,719	Vendor Quote	2	$9,437
	Instrumentation (from Valve and Instrument list)	$107,424	Vendor Quotes (VTS-1)	2	$214,848
	Isolation Valves	$8,000	Vendor Quote	2	$16,000
	Piping, Flanges, etc.	$13,000	Vendor Quote	1	$13,000
	Installation	$80,000	Estimate	1	$80,000
	Power Amplifier for add'l VTS	$40,000	$30K for VTS-1	2	$80,000
	Local Vacuum pumps	$3,500	Vendor Quote	2	$7,000
	Staging Area	$60,000	Jlab experience	1	$60,000
TOTAL					**$2,549,769**

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[1] R. Carcagno, “A test infrastructure concept to support the ILC Cavity R&D Program at Fermilab”, memo to Marc Ross, August 25, 2006.

[2] C. Ginsburg, “IB1 VTS FY07 Minimum Goals,” November 17, 2006.

[3] J. Ozelis, “ILC Cavity Vertical Production Test: Process Flow and Procedures for VTS@IB1,” Rev. 1, October 9, 2006.

[4] L. Lilje, “ILC R&D Board Task Force on High Gradients (S0/S1) – Definition of Cavity Tests,” L. Lilje, July 27, 2006.

[5] C. Ginsburg, “DESY/TTF RF Test Times for Q vs E,” November 17, 2006.

[6] Y. Huang, J. Ozelis, “Performance Analysis and Requirements of the ILC Vertical Cavity Test Stand Cryogenic System at IB1,” TD-06-012, May 3, 2006.

[7] T. Peterson, “MTF Refrigerator Liquefaction Rate Notes,” September 17, 1998