An Assessment of the Hall D Magnet Work Scope at JLAB

April 5 , 2000

Introduction

The MEGA/LASS Super Conducting Solenoid was inspected at LANSCE on March 9h and 10th. The overall condition of the magnet was found to be very good and worthy of the effort to relocate it to JLAB for eventual use in Hall D. Indeed ,there is a very high probability that the magnet system could be re-activated in place at LANSCE (with some effort) or moved to JLAB's Test Lab and re-assembled and re-activated (with greater effort) in its present state. Nevertheless the magnet is 30 years old and will require both maintenance and modernization of systems to allow its efficient , reliable and safe use at JLAB. These improvements ,if implemented will require the replacement of the cryo-interface box affectionately known as "Puffing Billy". This recommendation will result in an opportunity to optimize the overall project cost because the present location of "Puffing Billy" sets the overall building height. A relocated cryo-box(to beam right) would lower the required building height by 10 feet without losing any useful volume or capability. The added benefits of this relocation are that the cryogens are now outside of Hall D proper thus removing a major source of ODH hazard from Hall D , the space above the MEGA magnet is now totally open for other uses such as line-of-sight shielding etc. and the new location would allow 24 hour " unrestricted" access to the Solenoids controls ,instrumentation, cryogenics and DC power. The proposed relocation of the cryo-interface box is shown in Figures one ,Plan view and Figure two , elevation view. Figure three shows a cross section of Hall D with Puffing Billy in its nominal location for comparison.

The MEGA/LASS Solenoid was designed and built some 30 years ago. Many of its systems date to the late 70's and mid 80's.The power supply , electronics , instrumentation and interlock PLC are all very dated. Furthermore the magnet had a dedicated small Helium refrigerator so it has no cryogenic controls ! The magnet was operated from local analogue knobs , dials , gauges, switches and manual valves. Data Logging was by a person writing extensive tables in a paper log book, Cryogenic operations consisted of tuning the refrigerator manually to match the output to the load. The magnet was required to be vacuum pumped continuously by four large diffusion pumps. There are also non-code relief valves. The state of preservation of all these systems is very good but they represent a large future liability if not modernized. Obviously known problems and broken or irreplaceable items must be repaired or substituted .Other items must be brought up to contemporary safety and operating standards. Finally a fully remote and modern control and data logging interface must be substituted for the strictly hands on system presently in place.

Recommended Modifications

The following is a list of items somewhat generalized by subsystem that are part of this proposed Modification plan for the D/MEGA/LASS Magnet. The detailed assessment that follows provides the motivation and benefits of the proposed modifications . Clearly some details are preliminary due to lack of specific knowledge of present functionality of items at the lowest WBS level of organization . This does not effect the conclusion that there will be a significant effort at JLAB to place the Hall D/MEGA/LASS magnet in service safely , reliably and efficiently in an overall optimized configuration.

Magnet System Modification

Items	hardware cost	labor cost
Cryobox and transfer tube	150 K$	
Magnet adaptor box	30 K$	
DC Power system	50 K$	
I&C hardware	100 K$	
Cabling and feed-thrus	35 K$	
Vacuum system	25 K$	
End &Design (1MYR)		75 K$
Coil Maintenance (2 MYR)		100 K$
Cryo-modifications (1 MYR)		50 K$
I&C Software (1 MYR)		100 K$
Testing (1MYR)		75 K$
Electrical work (1MYR)		50 K$
Totals	390 K$	450 K$

This above list of modifications does not include the costs of magnet dismantling at LANSCE , shipping to JLAB , re-assembly in the Test Lab or final assembly in Hall D. These items are summarized in appendix A.

Further details of what is and is not included in the above modifications is in Appendix B

Detailed Magnet System Assessment

Cryogenics

The cryogenics for MEGA/LASS consisted of a large vessel know as "Puffing Billy" so named in reference to its visual similarity to the second steam engine to run in Great Britain after Stevensons Rocket. It was not named for some sailor emitting noxious gas from all ends in a state of permanent disarray as I had originally envisioned when first confronted with this quaint name. "Billy" consists of a large Helium tank , a service turret with external connections and four connection ports for each of the four coils.
The Large ~100 liter Helium tank inside "Billy" was designed for internal maintenance! A Large O-Ring sealed vacuum can covers all of it and can be removed for working inside. The Helium Vessel has a grind-able TIG weld seal at each end so access to the Helium tank is easily achieved. Inside there are brackets that receive planks so that service personnel can sit , kneel of lay down with some ease while working inside. The SC Bus and some instrumentation are access-able this way as is the bottom of the current leads.

Puffing Billy does not have any cryogenic flow control valves or shut-off valves except the manual valve that redirects gas during cool down. LN2 flow is regulated using a fixed speed pump .The LN2 current lead intercept is no longer used. This arrangement was selected based on the use of a dedicated cryoplant at both SLAC and LANSCE. This operating mode is not preferred at JLAB where all Helium and Nitrogen comes from large efficient centralized plants that are operated automatically completely unattended. A new cryo-reservoir interface box is required for the MEGA magnet to operate at JLAB.
There are already 4 cryo-reservoir interface boxes at JLAB with three more of a near identical design due this year. Thus a standard prototype JLAB reservoir exists and commercially made copies are easily available and affordable. Figure four is a typical example of a cryo-reservoir.

LN2 system

The LN2 Reservoir was removed at SLAC from Puffing Billy early on and an external LN2 circulating pump substituted. This was to eliminate a problem with a poor quality LN2 delivery system that caused unsatisfactory performance of the original, as designed LN2 Thermal syphon circulation system. All thirteen SC magnets at JLAB use LN2 thermal-syphon circulation and this is clearly the preferred and most efficient system. The replacement of the cryo-reservoir would involve restoring the original operating mode of the LN2 shield.

Cryogenic Bayonets

The cryogenic connections for the MEGA Magnet consists of a pair of bayonet adapters for Helium supply and return of a size and design similar to JLAB's standard but differing in size and construction details. They have ball valve shutoffs but do not have the set of pump/purge/relief ports that JLAB uses nor do they have the chevron seals above the ball valve. The bayonets are adequately sized for the direct cooling method that was used at SLAC and LANSCE. There is no LN2 supply bayonet nor is there a separate cool down gas bayonet. LN2 supply and return are through typical "pant legs" . There is no separate cool down line .The ports to inject LN2 around the current leads still exist.

Cryogenic valves and control

The only Helium Control valves on Billy are a set of manual valves for the purpose of routing cold Helium during cool down to the bottom of the coils. Exhaust cool down Helium gas returns through the Cold Helium return Bayonet while cool down Helium supply was through the Cold Helium Supply Bayonet.

The magnet was designed to be cooled by dumping Liquid Helium directly into the coils. Transition to level control was accomplished by closing the manual valves and hoping that the transient was not too severe. There was no way of regulating the rate of cooling between the four coils and the thermometry was of inadequate accuracy to compare the transition temperature of each coil. Normal operation consisted Of maintaining a liquid level ~ 10 % in "Billy" by tuning the refrigerator to match the consumption manually. The coils were bath cooled by the 10 % head. The open design of the coil cryostats permits Helium bubbles to rise to the free surface in the reservoir.

The LN2 shields were originally designed to be cooled by thermal syphon from a small separate LN2 reservoir in Billy. This failed due to the very low quality of LN2 delivered so the reservoir was removed and a pumped circulator was installed. This LN2 pump remains today.

Vacuum system

The MEGA Magnet vacuum system consists of two 12 inch oil diffusion pumps and a pair of roughing pumps. Each of the four coils and "Billy" has a separate pump line that exits between the yoke segments. The insulating vacuum was required to be pumped continuously due to various leaks. The diffusion pumps were state of the art in 1970 so hopefully they were selected for that reason rather than for their ability to pump Helium well! The pumps have been off for five years and it is unknown under what atmosphere they were left.

Coils

The four coil cryostats of the MEGA Magnet are each subdivided internally to achieve the desired field flatness. Coil one has 5 sub-coils , coil two has 4 sub-coils , coil three has 3 sub-coils and coil four has 2 sub-coils. In general the sub-coils are all of different size and amp-turns. Figure five is a cross section that illustrates the internal construction while figure six is a cross section in more detail of coil four that illustrates the method of closure of the Helium vessel . The Helium vessels of all magnet coils are closed by a lid held on by "c" clips and a very thin fusion weld on a grind-able raised lip. In short they were built to be easily opened for maintenance and repair. The leak tight state of the four coils is unknown except for statements by LANSCE staff that all serious leaks were fixed. The SLAC staff stated that one of the four coils had a serious Helium leak that was found and repaired.

The four coils are suspended inside the vacuum tanks four support rods and by a large number of studs that encircle each coil. These studs also support the LN2 shields. Four of the support studs in each coil are instrumented as strain studs to ensure that the coils and yokes are properly aligned. It is unclear if there exists temperature or voltage taps located inside of each coil or if all internal instrumentation is confined to Billy.

LN2 Shields

The LN2 Shields consist of a product called "Panel-coil". They are formed from two sheets of copper soft soldered together to form a pattern. This pattern is inflated after soldering. The edge is forced open and a tube is brazed into the resulting diamond shaped opening. Leaks at the tube penetration were very common and still persist. It is also likely that edge leaks exist also. Copper and soft solder can corrode with time and soft solder is not the most reliable cryogenic sealing technique. The shields are a known source of leaks and have resisted 30 years of effort to find and fix all of them. The vacuum level of the MEGA Magnet when last used was adequate with continuous pumping for operation .The Ln2 shields should be repaired or replaced as needed to allow operation free from the necessity of continuous vacuum pumping.

Vacuum Vessel

The MEGA Magnet Vacuum vessel is a welded stainless steel donut shaped structure that is closed with an O-ring sealed lid and bolts. It is very easy to access the interior for maintenance. The o-rings are not newer than 1985 and some may date to the 1970's.The present leak tight status is not know except for statements by LANSCE staff that most leaks were found and that vacuum did not present a hindrance to operations. The pumping system was required to be on all the time .

Internal piping

The magnet internal piping consists of a cool down tube that routes Helium to the bottom of each of the four coils. In the present configuration there is no method to regulate the flow to the four coils to insure an even cool down rate. This rate is governed by the different masses of the four coils. There are valves that select either cool down flow or reservoir filling (top or bottom fill). Each of the four coils has a large tube that contains the leads and connect to the bottom of Puffing Billy. These permit gravity fill and bubble venting in the same tube. This system appears to work. Regulating the cool down rate and equality of rate would seem to be desirable additions as well as incorporating the variable temperature cool down used in Hall C .
The installed Helium piping in the coils is probably adequate but the piping and valves in Billy may require updating especially the valves as they are only manual.

LN2 is distributed to the panels by a network of stainless tubes that were designed for natural convection Circulation and are now fed by a pump system. Reversion to the reservoir fed natural circulation system would be desirable as it would eliminate a maintenance item and use LN2 more efficiently. LN2 consumption was cited as excessive by the designers and users.

Pressure Relief Piping – Internal

The size of the piping between the coils and Billy are fixed by the available space between the yoke segments and the need to have adequate insulation. The designers raised a concern about the adequacy of these tubes relative to loss of vacuum pressure rise. A thorough re-evaluation will certainly be required And perhaps a reengineering of these connections made.

Internal Wiring

The state of internal wiring , insulation used redundancy and present functionality are unknown. These systems must be fully checked and upgraded or repaired as needed. The designers and users stated that these wires were fine and fragile.

Current Leads

The MEGA Magnet uses American Magnetics Inc. commercial 3000 amp current leads. The oversized leads were selected to provide some margin against lead burnout at the expense of cryogenic efficiency. The original leads were LN2 intercepted by a jacket surrounding the Helium filled lead chamber. Due to an over pressure accident with the LN2 one of the current leads was found to be crushed , overheated and damaged and was eventually replaced by LANSCE. They did not use the LN2 again to avoid a repeat incident. The LN2 was put in to reduce the Helium consumption of the oversized leads and to reduce the heat load imposed by the leads being inserted too far into the Helium storage reservoir. " Billy " was operated throughout its lifetime at less than 10 % capacity (almost empty all the time) to avoid the heat losses associated with the leads being inserted too far.

Strain Studs

Each of the four coils have four instrumented support posts as strain studs. Some are known to have failed or be out of calibration. They are all 1970's vintage so replacement must be considered. These are considered by the SLAC design staff and LANSCE operating staff to be essential for verifying the correct alignment and functioning of the four coils.

Helium Thermometers

The MEGA magnet uses Allen Bradley 270ohm carbon resistors for Helium thermometers. These devices can achieve good accuracy with the proper electronics and calibrations , have reasonable tolerance of magnetic fields and are somewhat susceptible to radiation damage. This radiation damage results in accumulated strain that alters the calibration which can be annealed away by warming to room temperature occasionally. The electronics for these thermometers is an unknown at this stage so further investigation is needed. The temperature electronics if any is certainly a good candidate for upgrading and integration into a data logger with remote readout capability. There is no information about the accuracy of the installed system nor are the exact locations of the thermometers known. A full evaluation for accuracy and adequacy will be required.

Nitrogen Thermometers

The MEGA Magnet uses Platinum resistance thermometers for monitoring LN2 temperatures and above. The staff identified these as inaccurate and good candidates for replacement with PT100's. The location and adequacy of the LN2 level temp monitoring is unknown as is the present functionality . The electronics ,calibration and accuracy are also not known other than remarks above.These are also candidates for incorporation into a data logger and controls as required.

Voltage Taps

The MEGA Magnet has some level of voltage monitoring located apparently in Billy. The taps are located between the splices and check each of the four coils and the two current leads. There are no taps inside the coils to check voltage on the sub-coils. It is unclear how the voltage detection works as none of the four coils are equal so comparison methods cannot easily work. The sensitivity and present functionality of the system needs evaluation. It is not know if the voltage taps are adequately protected with current limiting resistors.

Voltage Tap Feed Thrus

The voltage tap feed thrus are of an unknown design with an unknown voltage rating. The feed thrus appear to be similar to the instrument feed thrus and are o-ring sealed.

Instrumentation Feed Thrus

These are similar to the above discussed voltage tap feed thrus.

Electronics and Instrumentation

The electronics is all vintage 1970's and early 80's. Its present state of functionality is unknown. Obviously a serious look at the present service-ability must be made . Many of the components will certainly be found to be no longer in production and may not be repairable. Adaptability to remote control and data logging are other important considerations as well as accuracy and safety issues consistent with contemporary standards. The electronics was monitored by reading dials and writing numbers in a log book. That these logs survived is remarkable and preserves the operational history in a unique way.

The instrumentation scheme is not yet known to a certainty. Whether the sensors are read as voltages or are calibrated online, whether there are independent readouts or are DVM's required in some or many cases and some data are present on pneumatic gauges or flow-meters that are read visually .

Interlocks

The MEGA Magnet uses an Allen Bradley PLC for interlocks. The device is mounted inside a NEMA 2 by 3 by 1 foot enclosure and is of unknown heritage .It is a standard rugged industrial PLC but is of unknown age and model. The present functionality and usefulness will have to be evaluated especially the service-ability and integration into the final magnets control system.

Controls

The MEGA Magnet was controlled entirely by hand. There is no remote operating capability and no data logging . The installation at LANSCE permitted access to control areas of the magnet and cryogenics even during periods when the beam was on. Thus routine system monitoring , adjustments, data logging and setting current could be freely performed. This situation though desirable is certainly impossible at JLAB.

DC Power

The power supply is a commercial P=EI (Power Electronics Inc.) supply with a regulation of 0.1 %. It was operated locally from front panel controls. There is a modern current and voltage readout attached to the front of the cabinet that appears to be a more recent addition. The power supply is probably as old as the magnet and seems to have no remote control capability except for some basic interlock functions. At a regulation of 0.1 % it will eat 10 % of the allowed Hall D momentum resolution budget which may be acceptable. The power supply long term drift is unknown at this time. The power supply was used at LANSCE for the three coil configuration. It will ramp at ¾ the rate for the four coil configuration. The current rating may be adequate for Hall D use if the supply is the original SLAC power supply .The Power supply control interface will likely require a full remote capability. Acceptable modifications may be possible. Safety issues concerning interlocking and magnet protection will have to be reviewed at contemporary standards. Obviously a serious comparison between a new modern supply and the present supply with modifications will be an essential part of the final cost effective solution. Although the present supply will be adequate for initial testing at JLAB the final installation in Hall D will likely require a replacement..

Dump Circuit

The MEGA Magnet energy dump consists of a slow dump and a water bath fast dump. The users of the magnet also indicated that the power supply could ramp down also. The designers stated that the fast dump was never (thankfully) used. The concern was for the higher voltage and thus faster discharge rate. The slow dump and power supply were used routinely and several of the staff indicated that the discharge rate was not much slower than the fast dump. The power supply inversion discharge is actually faster than the slow dump because the linear ramp down actually reduces the magnet current to zero faster than the exponential slow dump resistor. The slow dump is a stainless air cooled resistor in a standard 19 inch rack . The fast dump is a stainless coil in a water tank. The reliability of this and the ultimate dependency on the water level will need a review to insure that the dump is safe to use and of a fail safe design. The dump circuits are all homemade and thus a complete check for NEC compliance will be necessary before use at JLAB can be authorized.

Relief Valves

The relief valves on the cryogenic spaces are a mixture of commercial and homemade devices. The homemade valves certainly do not meet the letter of the ASME Code section VIII. The SLAC- made valve is referred to as the " doomsday " valve for obvious reasons. It was never used much to the relief of its designers. Its existence is based on an extremely conservative analysis that indicated that the internal piping was inadequate in a severe loss of vacuum incident. This analysis postulated that an external accident would severe one of the 4 inch vacuum lines causing loss of vacuum and simultaneous stripping of all MLI super insulation from the cryostats. The resulting high heat flux leads to a predicted overpressure condition. As there are five large vacuum pump lines the postulated accident is plausible however the simultaneous loss of all MLI just does not happen either in real accidents or in staged experiments. The worst case conditions assumed above results in a heat flux that is too high compared to actual measurements and is thus too extreme. Nevertheless the analysis identified inadequate internal piping that required a larger relief. A re-analysis with best contemporary information is essential. Modifications of piping and installation of ASME Code compliant relief valves as needed should follow.

Appendix A – Shipping , dismantling and erection costs (April 4,2000)

Disassembly ,packing and loading at LANSCE (labor and equipment for 14 days)	124 K$
Shipping to JLAB (14 loads/13 feet wide , labor ,equipment ,escorts and permits)	110 K$
Unloading in the Test Lab at JLAB (Labor and equipment)	33 K$
Re-assembly in Test Lab (Labor with JLAB crane)	50 K$
Final relocation from Test Lab to Hall D	
Disassembly in Test LAB (labor with JLAB crane)	40 K$
Moving and unloading in Hall D	30 K$
Re-assembly in Hall D (Labor , JLAB crane , contractor equipment)	50 K$
Total	**437 K$**

Appendix B – Magnet system modifications details

Items

Cryo-box and transfer tube
    Cryo-box , control valves , actuators , current leads , bayonets , reservoirs ,internal instruments, relief valves and cryogenic supply and cold current bus tube to Magnet
Cryo adapter to MEGA Magnet
    Includes the cold current bus splice box and cryogenic piping adapter to join the four coils to the new cryo-box supply tube
DC Power system
    10V 2000 amp DC supply .01% , dump circuits and housings
I&C hardware
    External electronics , signal conditioners, local display , PLC controller , EPICS interface
Cabling and feed-thrus
    Materials cost for new cables , connectors , feedthrus , DC bus etc.
Vacuum system
    1000 L/s turbo pump station
Engineering and design
    Labor to design the modifications to the MEGA Magnet at JLAB
Coil Maintenance
    Labor to repair and recondition coils including repairing leaks , replacing wiring , sensors, O-rings, Repairing LN2 shields and modifications to internal piping .
    Cost of internal sensors and wiring, MLI , internal piping etc.
Cryo-modifications
    Labor to modify the interface between the four coils and the cryo-box
I&C Software
    Programming labor to write the complete Magnet control system software
Testing
    Labor to cool down and test the MEGA magnet for one extended period of time
    This assumes a largely automatic operation.
Electrical work
    Labor to fabricate , test and install new cables and DC bus

Not included in the above

NMR Field regulation
Precision current transductor
New LN2 shields
Labor and equipment for magnet mapping
Cost of Test Lab site Modifications for Mega Magnet testing
Cryogenic transfer lines to Hall D
U-Tubes to connect the magnet to transfer lines in either Test Lab or Hall D
Cooldown heat exchanger
Gas piping in Hall D or Test Lab

Most importantly the cost of **not doing** the modifications is not included !!

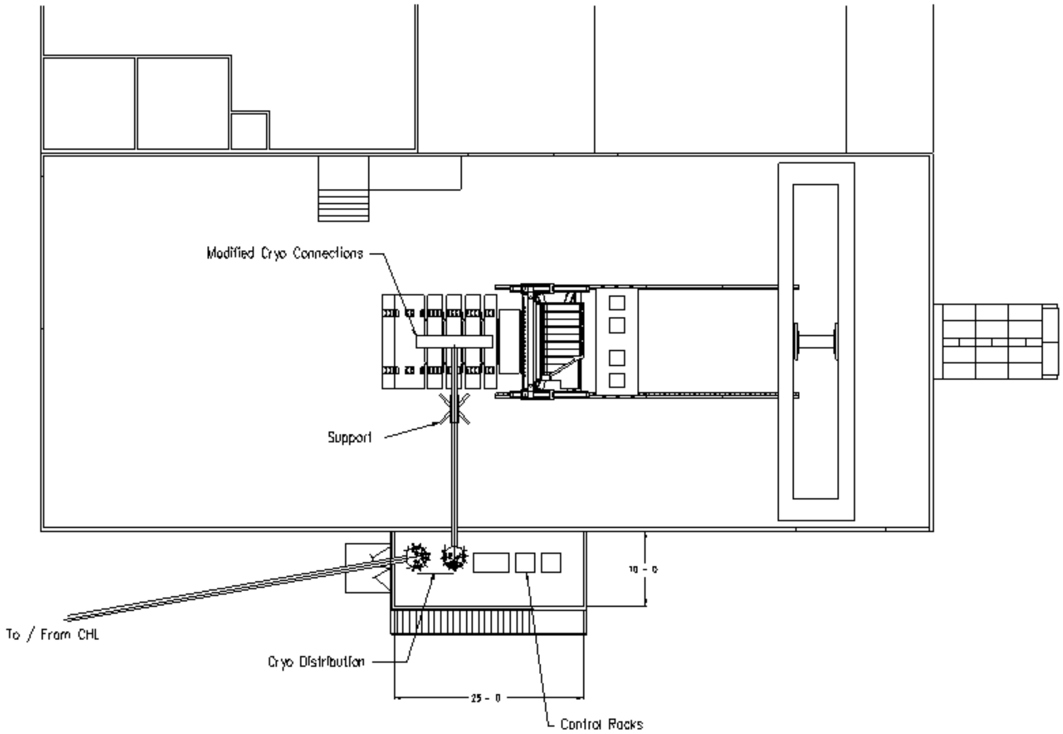

Figure one   Plan View Hall D with relocated cryo-can

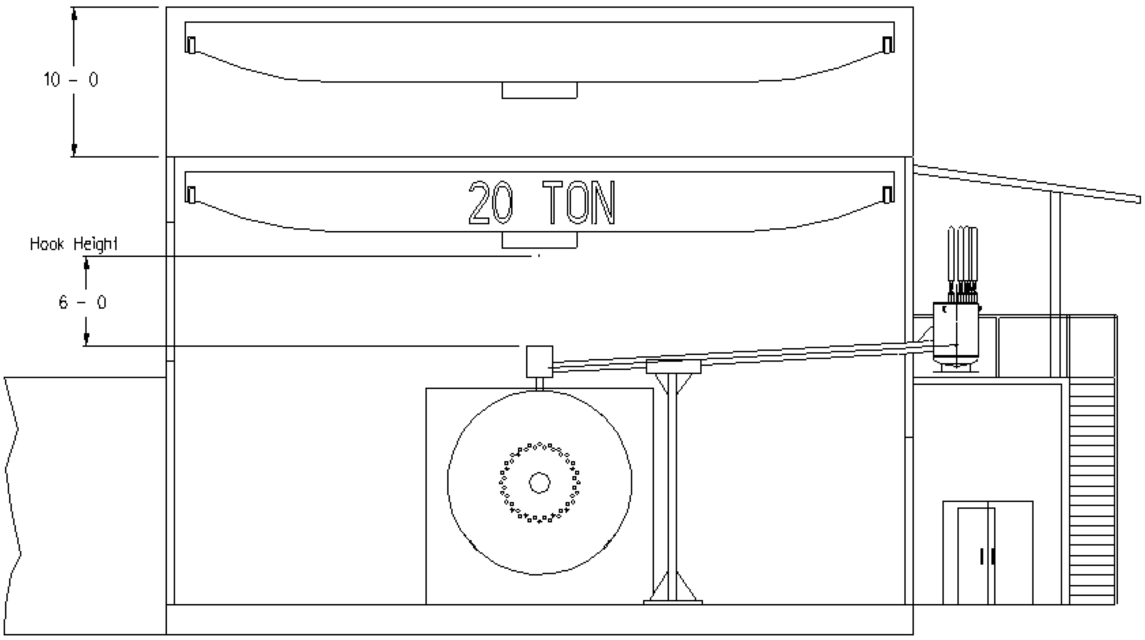

Figure two   Elevation view Hall D with relocated Cryo- can

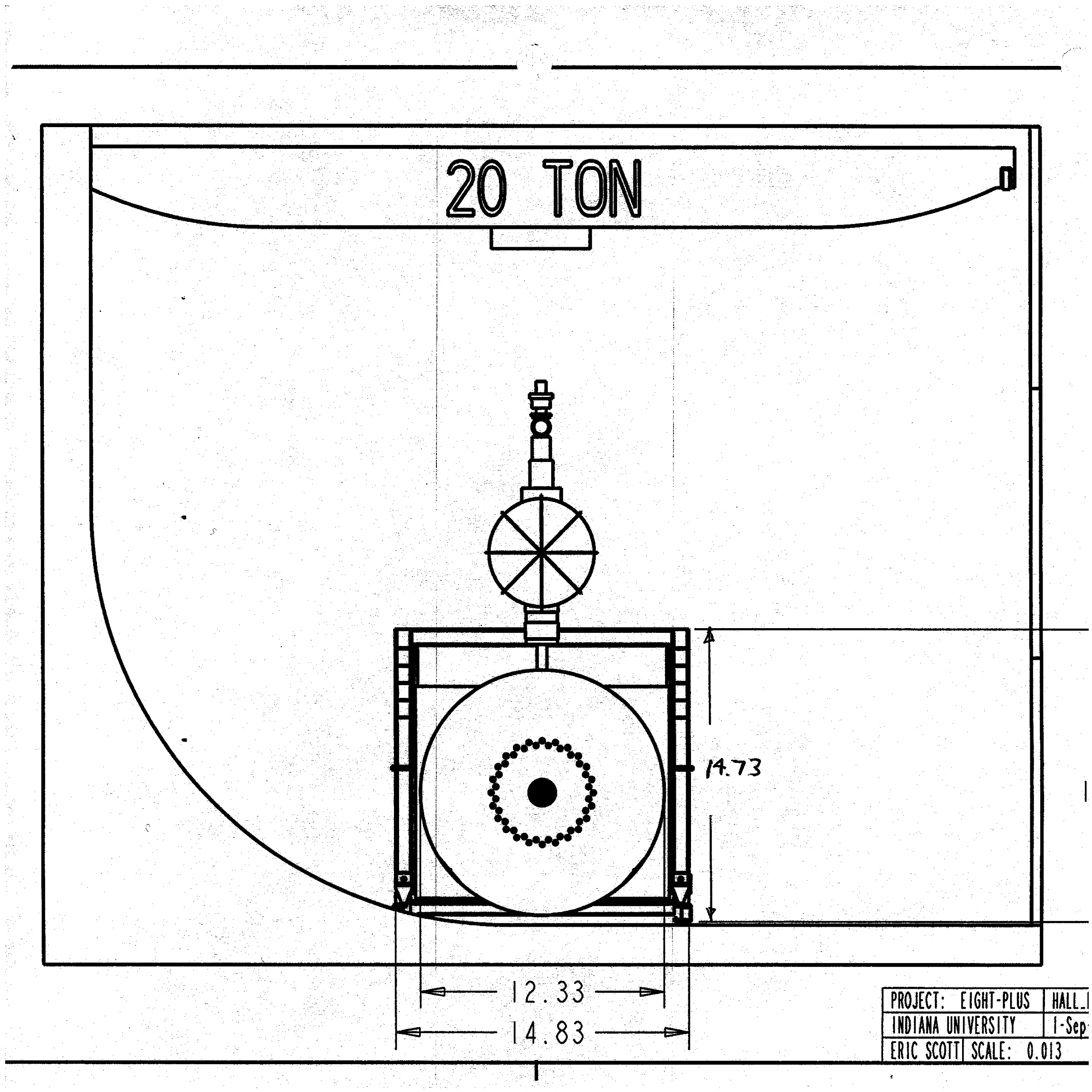

Figure three – Hall D with Puffing Billy

Figure four-typical JLAB cryocan "to be added"

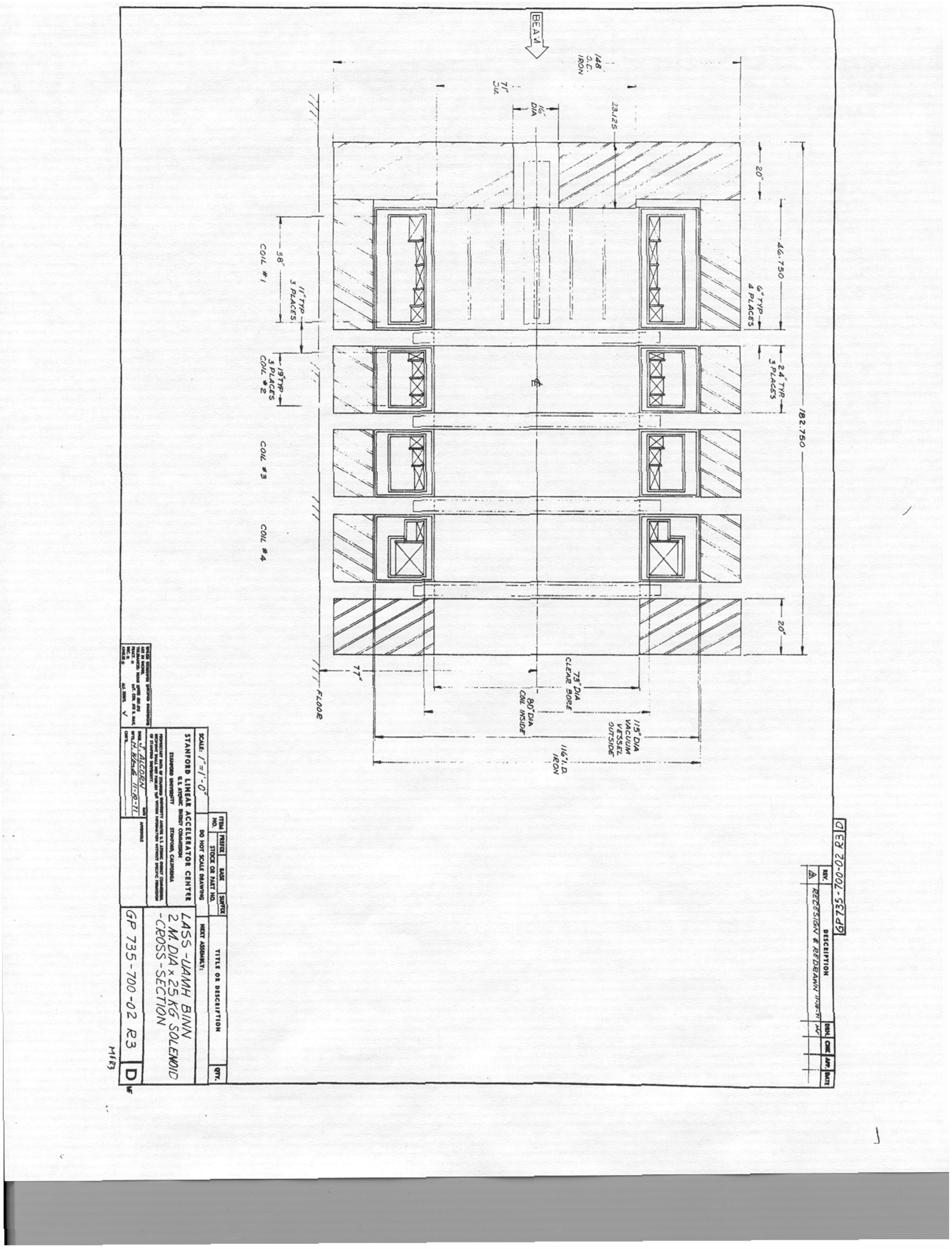

Figure five – MEGA/LASS / Hall D Solenoid cross section

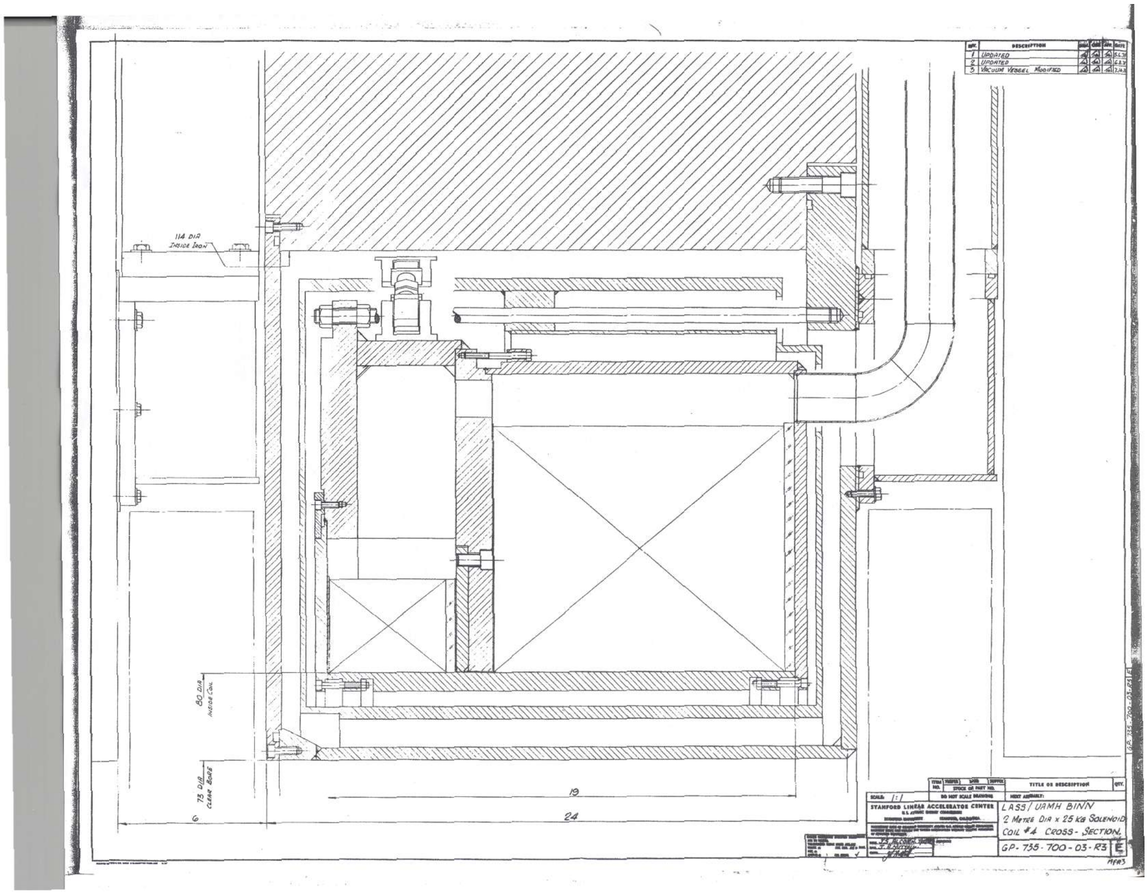

Figure six – MEGA/LASS /Hall D Solenoid coil four cross section