Review of MICE Spectrometer Solenoid repair plan

First meeting – Phone call of October 27th 2010

Some specific requests to the solenoid team for further documents/information:

1) **Quench protection and electrical circuits**

1.1) An electrical scheme of each individual circuit - a sketch is indicated on slide 5 of the presentation given by Soren Prestemon. But together with the characteristics of the circuits (nominal and maximum current, time constants) we should get information on the type of superconductor used in the bus and in the magnets (cross section, filling factor, type and possibly characteristics of the stabilizer), on the exact location and configuration of all electrical joints, on the exact location of all voltage taps already available or envisaged to be added in the system, on the type of cooling of all superconducting elements. (We possibly understood that the current leads are in vacuum, and somewhere there is a leak-tight electrical transition to the liquid helium environment, where all the other superconducting parts are located).
Soren Prestemon has compiled some of this information and is meeting with the vendor tomorrow (11/19) to collect additional information. The area around the vacuum-to-helium feedthroughs is documented in MICE Note 324.

1.2) A scheme indicating which signals were used in the past for protection of the leads, of the bus and of the magnets, and what is planned to be done in the future - monitoring is a separate issue;
During all previous testing of the magnets, there was no active use of any of the voltage tap signals for protection of the magnet leads or coils. While the coil quench protection system is completely passive, the possible need for a monitoring and protection system for the leads is recognized. Soren Prestemon will be addressing this topic in his analysis.

1.3) The proposal, if it exists, for the quench detection voltages;
The high internal voltages, generated by the normal zone voltage coupled with the coil self inductance, is not actually seen by neighboring conductors, nor to ground. However quantifying the actual voltages that the insulation is subjected to requires more sophisticated simulations. We are in the process of developing models for the dynamic simulation of quenches in the system, as suggested by the reviewers. The Vector Fields software module "Quench" is being purchased by LBNL to allow more comprehensive modeling. Soren Prestemon is currently in the process of developing the model.

1.4) Information on which actions are taken in case of resistive transition of the bus and of the HTS part of the lead (fast or slow discharge);
Please refer to the answer to 1.2 above.

1.5) Information on the characteristics of the HTS part of the lead (number of tapes, electrical characteristics, amount of stabilizer).

A complete list of cross-sections, joints, and voltage taps is currently being generated. We will document how each component is cooled, as well as modifications we intend to make to the cooling/stabilization of certain sections of leads. The magnet protection scheme that has been used to date, as well as any modifications to the scheme that will be proposed by the MICE Team, will be presented.

2) CERNOX and other low-temperature sensors

2.1) There was considerable doubt in March about the usefulness of existing CERNOX and other low-temperature sensors fitted to the cold mass, due to confused or missing calibration data, and faulty sensors. Which of the existing low-temperature sensors on each of the magnets are reliable? What can be done about the others?

At this point, the only sensors that are in doubt are the Cernoxes that are within the cold mass and are not accessible. All other sensors are on the outside and can be replaced as necessary (there were two that were apparently not reading properly on Magnet 2B). The following sensors are inside the cold mass: TRX01 and TRX02 (Cernox), and TPR01 (platinum resistor). The Cernox sensors were working but probably cannot be trusted down to a small fraction of a degree.

2.2) Full details are required regarding the instrumentation planned for the HTS and LTS leads and their heat-intercepts, which require comprehensive monitoring prior to and during powering of the magnet.

There will be three full sets of voltage taps on the 8 leads internal to the magnet (these were all in place for Magnet 2B). These voltage taps are located as follows: on the upper end of the HTS leads, on the lower end of the HTS leads, and on the coil leads internal to the cold mass (refer to the instrumentation drawing). During the previous tests, these voltages could be (and were) monitored manually at various stages, but there was not a fast data logging system in place to provide data during a quench. For future tests, we will likely use a series of PicoLog 1216 modules connected to a PC via USB. This type of system was recommended by Mike Courthold of RAL who has used it for a similar application.

2.3) A complete set of the temperature logged data during the test in March is required.

During the Magnet 2B testing, 15 channels of temperature data were recorded every 5 minutes over a period of 12 days from the start of cooldown through the training of the magnet. All of this data is contained in the spreadsheet at the following link:
http://www-eng.lbl.gov/~spvirostek/Muon/October_2010_Review/Temperature_Data/

The associated instrumentation drawing is included in the same folder for reference.

3) Thermal model

(3.1) Are there current plans or ideas for a low impedance path for vacuum pumping the volume between the shield and the cold mass? Of course, the radiation heat load on the cold mass through this path must be considered.

This will be added using a design of an optical trap heat anchored thermally to the screen. The trap increases the heat load to the shield very slightly (≈ 0.5 W), but does not add to the heat load of the cold mass. The impedance for gas flow is reasonably low both in the laminar and in the molecular flow regimes.

(3.2) Please revise the table on page 4 of the heat load review talk to have a column for the expected heat loads on the new revised design. It is expected that some entries may have ranges or question marks.

Here is the revised table, showing in the fifth column a rather optimistic estimate of what could be expected if the cryostat reassembly will be done carefully along the lines suggested in the review meeting.

Source of heat	MICE Note 236, Ref. [1]	Test 2B conditions with shield at 98 K (Sanders, Ref. [2])	Update of September 2010	Nov 2010: Shield 60 K, no res. gas, low rad trgh pipes, 5% duty cycl probes	Item Nb, see Notes
	(W)	(W)	(W)	(W)	
Radiation from shield	0.050	0.252	1.002	0.175	1
Radiation from 300 K	0.000	1.000	1.000	0.500	2
Support rods	0.310	1.100	1.100	0.188	3
Neck tubes	0.060	0.060	0.060	0.060	4
Cooler sleeves	0.750	0.750	0.750	0.750	5
Instrument wires	0.050	0.310	0.050	0.050	6
Magnet leads	0.870	0.870	0.870	0.870	7
SC wire joints	0.400	0.400	0.400	0.100	8
Residual gases	0.000	0.000	0.110	0.000	9
Radiation through pipes	0.000	0.250	0.500	0.200	10
LHe level probes	0.000	0.000	0.261	0.065	11
Cold shorts	0.000	0.000	0.000	0.000	12
Cryocooler underperformance	0.000	0.000	0.000	0.000	13
TAO + LHe fill line instability	0.000	0.000	0.000	0.000	14
Sum	**2.490**	**4.992**	**6.103**	**2.959**	

Notably, it has been assumed that the shield temperature will be 60 K except its bore tube that is assumed to be at 70 K (Note 1). The radiation leakage orifices were reduced to ½ everywhere (Note 2), and the support rods were heat sunk to 60 K (Note 3). The SC wire joints are assumed to have a more realistic and lower value (Note 8). The residual gas conduction was reduced to zero (Note 9), requiring excellent evacuation and no leaks. Radiation through pipes was cut down by installing optical traps (Note 10). The duty cycle of the level probes was reduced to

5% (Note 11). The sum is ≈ 3 W and gets close to the original design value (2.5 W); the sum depends strongly on the temperature of the thermal shield, and reaches 4.1 W if the shield temperature is 100 K.

(3.3) Please prepare another table similar to the table on page 4 of the heat load review talk for the heat loads on the shield. Include a column the expected heat loads on the new revised design. It is expected that some entries may have ranges or question marks. It is important however to identify all shield heat load sources in one table.

Source of heat	Heat load under Test 2B conditions	Notes
	(W)	
Radiation to outer cylinder (perfect MLI)	4.0	
Radiation to end plates (perfect MLI)	1.9	
Radiation to bore tube (dense MLI)	9.5	
Radiation through imperfections	12.5	
Radiation through bore tube gap	3.8	
Conduction along shield supports	0.6	8 Prepreg laminate supports each with 2 rods 0.99 cm x 0.3 cm, length 5.32 cm
Heat sinks of cold mass supports	6.4	8 Prepreg laminate supports each with 4 rods 3.9 cm x 0.8 cm, length 10 cm
Heat sinks of pipework	2.0	
Heat sinks of wires	0.2	
Heat sinks of magnet leads (0 A)	42.9	8 Cu leads of 5 mm diam, 300 mm length
Total	**83.8**	

Here is the table showing the breakdown to the various sources of heat load to the shield, under the following assumptions:

- The first three lines show the heat leak through the various parts of MLI blankets, assuming a normal density of 20 layers/cm everywhere, except for the bore tube where the density is 50 layers/cm.
- The effective orifice are of 500 cm^2 was assumed for the MLI imperfections
- The bore tube gaps were assumed to have an effective orifice area of 150 cm^2.
- The real dimensions of the Prepreg laminate supports and its thermal conductivity integral measured by Wang were used, together with the accurate dimensions shown in the Notes column.
- The dimensions of the magnet leads are certainly well known, but I did not have accurate values available. For the integral, the low end was assumed at 100 K, and high end at 300 K.
- The sum has a large unexplained deficiency comparing with the data of Test 2B. Notably, poor vacuum cannot explain a substantial fraction of the missing 200 W. Mechanical contact with the vacuum chamber would need to be hard pressed, and would have caused a frost spot. Poor thermal conduction along the Al 6061 alloy structure of the shield cannot contribute much to the heat load to the shield itself. The deficiency between the expected and measured heat load to the shield is perhaps the most curious mystery of the spectrometer solenoid.

- Can there be a deficient contact to the first stages of all of the cryocoolers? This is only possible if the copper plate would move down substantially (relative to the cryocoolers) when the magnet is cooled down.
- Is it possible that the shield never reached equilibrium temperature during the test 2B? Is there data showing the evolution of the shield temperature during the Test 2B?

(3.4) Please provide enough information on the 2B magnet for the connections between the copper plate and the shield to calculate the heat flow using the measured temperatures. We wish to calculate the heat flow similar to what was done for magnet 2A in Mice note 285 , page 3, item i. If drawings do not exist please provide sketches or descriptions of the material and dimensions.
A series of photos of the connection is provided at the following link:
http://www-eng.lbl.gov/~spvirostek/Muon/October_2010_Review/Shield_Connection/
The connection between the first stage copper plate and the shield consisted of the following:

- a series of 10 copper-to aluminum transitions (25 mm square) welded to the copper plate (2 sides) and welded to the vertical aluminum 6061 cylinders (single outside weld only) as shown in photo P9150552.jpg.
- vertical 6061 cylinders (clamshell arrangement) around each cooler are welded to the transitions and extend downwards
- 1100 aluminum flexible straps (10 each) connect to 6061 aluminum cylinders welded to the shield body (see photos)

A schematic diagram of one of these connections surrounding the cryocoolers is provided in the following file with descriptions of the materials and dimensions:
http://www-eng.lbl.gov/~spvirostek/Muon/October_2010_Review/Shield_Connection/

(3.5) Are there any noticeable defects in the magnet 2B connections between the copper plate and the shield, such as a cracked weld, that may have impeded heat flow?
The weakest connection in the series appears to be the welded joint between the clamshell aluminum cylinders and the small transition blocks that are welded to the copper plate (see previously mentioned photo). There were no reported defects or weld failures in any of these connections upon disassembly of the magnet.

(3.6) Does anyone recall if there any noticeable defects in the magnet 2A connections between the copper plate and the shield, such as a cracked weld, that may have impeded heat flow?
The same comments from 3.5 above apply here.

4) Cryocoolers

4.1) What are the dimensions of the Cryomech 415 cryocooler condenser? What is its outside diameter and height? How many vertical holes are there and what is the diameter? Please confirm that these holes are not blind, that they go completely through the copper.

- The condenser has the following dimensions:
- 92 mm outside diameter disk of copper, 38 mm tall
- 57 each 6 mm diameter through holes
- Photo available at the following link:

http://www-eng.lbl.gov/~spvirostek/Muon/October_2010_Review/Cooler_Condenser/

(4.2) What is the internal diameter of the tube the Cryomech 415 cryocooler condenser was inserted into?

98 mm ID

(4.3) How many of the cryocoolers used in the 2B test, had been tested individually by Wang NMR or LBNL? Did any of them have prior extensive operation? The review panel will be in contact with Cryomech and will confirm that they performance test all cryocoolers before shipping.

All cryocoolers used on all iterations of the magnets were tested off line using a single cooler test apparatus designed and fabricated by Wang NMR. Each cooler is run 24 to 48 hours during this testing. I believe all coolers used on the 2B testing were previously used on the Magnet 1 and 2A testing as well. Based on this, the Magnet 2B coolers would have previously been run for approximately 1200 hours each.

(4.4) What is the maximum temperature of the liquid helium that is acceptable for operation of the solenoid. The cooling capacity of a cryocooler (in Watts) increases with temperature.

In all cases, the magnets were cooled to the point where the cold mass was less than 5K. There were a series of sensors with various readings in general, but I believe these were always reading below the 5K number before the current was turned on.

(4.5) Based on the experiences of the 2B test, will there be a minimum required helium level for operation of the solenoid? This determines if the cryocoolers will be condensing superheated vapor or saturated vapor.

Previously, the ramp up of current began with the liquid level between about 60% full and completely full. With the boil-off that was occurring, the magnet could be as low as 50% full when the quench occurred. The plans for future testing are for the cold mass to be completely full before the current is introduced.

(4.6) In the 2B magnet test, how many holes (through which the helium had to flow) were between the plenum below the cryocoolers and the top of the helium space of the cold mass and what was the hole diameter? The review panel is aware of the plan to open up the flow path.

The three cooler connections at the top of the plenum were 98 mm diameter, and the two connections at the bottom of the plenum to the cold mass were 50 mm diameter.

(4.7) Are you aware of any realistic modes of cryocooler failures where the cryocooler 2nd stage degrades in performance but the 1st stage doesn't? Hypothetically If this event did occur would it be possible through the installed instrumentation to determine which of the five PT415 cryocooler's 2nd stage is not working properly?

Our only direct diagnostics on the coolers are the temperature sensors on the first and second stage cold heads. If there was a problem with one of the second stages, we would presumably see a temperature difference on that condenser. In the case of the cooling circuit not working properly (as with the blockage in Magnet 1), we could see lower than normal temperatures at the condenser (<4K), indicating that the cold heat is not receiving any heat and is not recondensing. The cooler compressors are also quite sensitive to operational problems such as insufficient cooling water flow or improper helium pressure and will trip off.

5) Drawings

5.1 Drawings of vacuum chamber, thermal shield, supports and turret. There is a high priority on these drawings, which could help understanding the mis-matching between effective and computed heat load at the first stage.

All of the drawings obtained from Wang to date are available either in the 2006 design book (http://www-eng.lbl.gov/~spvirostek/Muon/October_2010_Review/) or in the folder containing the latest AutoCAD drawings (http://www-eng.lbl.gov/~spvirostek/Muon/October_2010_Review/Latest_Wang_Dwgs/). Please note that there is a general lack of upper level assembly drawings that will make it difficult to locate all of the parts shown in the detail drawings. LBNL will be working to rectify this situation.

5.2 Drawing of cold mass cross-section with all dimensions, including ground, G10 spacers, interlayer electrical insulation, outer Al bobbin, bandage ring, LHe vessel, feed through, etc.

There is no single drawing that shows all of these details. There are drawings in the design book of the winding bobbin and cold mass covers. Other coil design parameters including insulation specs are given in the following table: Chapter II, Table II-1-1 (page 7).

5.3 Drawing of cold leads position inside and outside the coil sections, electrical insulation;

There do not appear to be any specific drawings of these areas of the cold mass. Any information that exists would be in the form of descriptions by the vendor in the 2006 design book.

5.4 Drawing of shunt resistors and cold diodes with corresponding insulation and space positions in the cold mass;
Some drawings of the requested components exist and are being obtained from the vendor and will be provided soon. Please note that Wang NMR considers any drawings and descriptions of the passive quench protection system to be proprietary and should be treated as such.

5.5 All leads cross-sections inside the coil, in space between coil-shunt, shunt-cold feed through, feed through-bottom HTS lead, and shunt resistor cross-section.
Mike Green's analysis of the lead failure contains much of the requested information regarding the configuration of the leads. The write up has been documented in MICE Note 324 and is also provided at the following link:
http://www-eng.lbl.gov/~spvirostek/Muon/October_2010_Review/MICE_Note_324/

6) Schedule and Organization

6.1 Please provide more information on the %FTE commitment of the people nominated for the various repair tasks. Please also indicate which tasks are most at risk from insufficient manpower.
The following is a list of individuals who will be actively involved in the completion and testing of the Spectrometer Solenoid magnets. The percent time indicates the nominal effort for each person over the next 9 months. The areas of responsibility are listed below each individual as well. Funding for the level of effort shown below has been approved through the US MAP Collaboration.

Steve Virostek (LBNL) - Sr. Mechanical Engineer - 50%
- overall project management
- some oversight of magnet assembly
- magnet training oversight
- documentation

Tapio Niinikoski (LBNL) - Sr. Cryogenic Engineer - 30% (at LBNL)
- CERN retiree, hired 1/2 time by LBNL
- magnet design analysis
- design modification recommendations
- some oversight of magnet assembly
- magnet training oversight

Roy Preece (RAL) - Mechanical Engineer - 50% (at LBNL)
- oversight of magnet assembly
- magnet training oversight
- Integration and documentation

Nanyang Li - Mechanical Engineer - 40%
- continuous oversight of magnet assembly
- magnet training oversight
- documentation

Soren Prestemon - Cryogenic Engineer - 25%
- magnet design analysis
- design modification recommendations
- occasional oversight of magnet assy

Vladimir Kashikhin (FNAL) – Engineer - 15%
- quench protection system analysis
- power supply systems

Controls Engineer (FNAL) - 15%
- quench protection system analysis
- power supply systems

Sisi Shan (LBNL) - Mechanical Engineering Student - 20%
- organization of magnet detail drawings
- development of magnet 3D CAD drawing

The primary area where manpower limitations may be an issue is oversight during the assembly of the magnets. While we have enough personnel to be present at the vendor during all of the fabrication steps, it is important to have the appropriate knowledgeable and experienced individuals on site during the critical operations. Tapio Niinikoski and Soren Prestemon can fulfill the majority of these needs, but there will likely be periods when neither of them is on site. We are currently exploring additional resources to help fill this gap.

A preliminary schedule has been put together with the help of Roy Preece from RAL that includes a detailed task list. The work on the first magnet begins on 12/16/10 in the schedule. Please note that this schedule is preliminary and has not been reviewed in detail with the vendor. At this point, the schedule only shows the tasks associated with the completion of the first magnet. The second magnet will undergo the same series of tasks and is generally expected to follow the first by 2 to 3 months. The possibility of completing both magnets in parallel has been considered. However, it is not likely that the vendor will have sufficient resources to complete the magnets in this manner without significantly slowing down the process of getting the first Spectrometer Solenoid delivered to MICE. Once a plan to proceed has been decided upon and approved, the details of the two magnet schedule will be agreed upon with the vendor any will take into account any manpower limitations. Both pdf and MP versions of the preliminary, one magnet schedule can be found at: http://www-eng.lbl.gov/~spvirostek/Muon/October_2010_Review/Schedule/