Genova, December 14th 2010

Report of the MICE Spectrometer Solenoid Review Committee analysing the repair plan

1. Introduction

This document contains all the information related to the review of the repair plan of the MICE spectrometer solenoids (SS).

The review panel were formed of external experts (Amalia Ballarino – CERN , Elwyn Baynham – ITER, Tom Bradshaw – STFC, Mike Courthold – STFC, Vladimir Kashikhin – Fermilab, Robert Sanders – Fermilab and Pasquale Fabbricatore acting as chair –INFN-Genova). MICE collaboration members attended the review (Alain Blondel – UNi Geneva, Alan Bross – FERMILAB and Andy Nichols – SFTC).

A web site has been created for collecting the information and exchanging opinions, http://indico.cern.ch/conferenceDisplay.py?confId=110250 . This web site contains the links to previous reviews (November 2009 and May 2010), review charge and phone meetings details. In particular in the phone meeting of October 27th the SS team presented the relevant documentation (status, analyses, repair plan, organization and schedule).

After the October 27th phone meeting, the review committee produced on November 11th the minutes of the meeting, including preliminary comments, remarks and questions (these minutes are available on the above review web site). The questions were answered in two steps on November 18th and 20th by Steve Virostek, coordinator of the SS team, through a specific document also accessible at the web site. More documentation (mostly of confidential nature) was made available at a LBNL web site (http://www-eng.lbl.gov/~spvirostek/Muon/October_2010_Review/).

On November 29th the committee had a closed session by phone for commenting the presented material and formulating recommendations.

The present document reports on the discussions held during the review and the conclusions drawn by the review board.

2. Review charge

The review charge was issued by the MICE collaboration since October 8th and contains 9 points as follows:

1. *To set a date to review and sign off on a complete set of assembly and part drawings of both spectrometer magnets.*
2. *To set a date to review and sign off on a revised set of thermal balance calculations that are strictly based on the above design.*
3. *To set a date to review and sign off on a magnet repair and reassembly plan indicating all "stop & inspect" points.*
4. *To review and comment on the repair project plan, including acceptance criteria at the necessary decision points (before undertaking repairs, before cool-down, before power-up, before release of the magnet) based on measurements on the magnets with the appropriate instrumentation, and comparison with thermal calculations predictions.*
5. *To confirm a date of December 1st, 2010 for acceptance of the repair plan by the Spectrometer Solenoid Review Committee.*
6. *To agree to a list of project deliverables and delivery dates. It is presumed that major delivery dates for these deliverables will be contained in (4).*
7. *To set the date of the formal repair plan review*
8. *Quench protection system & lead protection, part of item 4*
9. *Cool-down scheme – spec. in deliverables, operations manual*

List of deliverables

- *i) Repair project plan with resource loading, schedule float and milestone table (see above)*
- *ii) A set of construction drawings (before repair) of both magnets (see above)*
- *iii) A revised set of thermal balance calculations performed based on these drawings (see above)*
- *iv) CofG diagram and lifting/handling instructions*
- *v) Project resource table*
- *vi) Electrical specification, including circuit diagrams, etc*
- *vii) Dimensioned 2D Interface and envelope drawings, including all services requirements and external fiducial marks or features.*
- *viii) Instrumentation plan*
- *ix) Written specification of the magnet control system*
- *x) EU declaration of conformity for pressure system and vessel*
- *xi) Technical data file, including test results, material data, performance results and certification for all critical materials and equipment*

xii) A set of as-manufactured drawings of both magnets
xiii) Magnetic mapping plan of the magnets
xiv) Details of shipping to STFC, UK

The review committee has a couple of general comments regarding the review charge. There exist many updated details drawings by Wang NMR, but they are very difficult to understand, because updated assembly drawings are not yet ready and will be presumably finished only in a few months. Consequently: a) Point 1 of the review charge is in fact not achievable at the present time; b) Thermal calculations provided by the SS team (point 2 of review charge) are not strictly based on the above mentioned drawings.

The analysis of the documentation has taken some time and the clarification of some points has required iterations questions/answers with SS team. Consequently organised advice on repair plan was ready only by Dec 14th.

3. Documentation

The committee acknowledges (and thanks) the efforts of Steve Virostek and the SS team for assembling and coordinating a very large amount of documents (drawings, notes, presentations, design data and test measurements). It must be noted that as matter of facts this documentation is incomplete. The lack of as-built assembly drawings is the major problem, creating difficulties in the understanding of the problems encountered by the magnet.

4. General comments and organization of this review document

The committee has identified three critical areas of the Spectrometer Solenoid:

1) Protection of the coils, of the current leads and cold leads. It is not a coincidence that two major failures of the leads happened during the last two series of tests. In the future a failure of this kind will prevent the magnet operations and a long time (order of one year) would be again required for repairing the magnet.
2) Heat loads at 4.2 K. This is a critical aspect because a LHe boil-off would make on-site operations more difficult (and perhaps dangerous for the magnet itself), requiring dedicated and continuous manpower and resources for controlling the system and re-filling the cryostats.
3) Heat loads to the shield. Here, the criticality is related to lack of clear understanding of the problems and the present mis-match between the installed cooling power and calculated heat loads. This situation is a potential source of unknown problems.

In the following sections 5, 6 and 7 these three issues will be individually discussed. Comments will be made on the analyses provided by the SS team, followed by recommendations of the review committee. In section 8 the repair plan is reviewed on the basis of the points discussed in sections 5 to 7. Sections 9 and 10 report comments about manpower, organization and schedule.

5. Quench, protection and current leads

5.1 Comments on the quench analyses done by SS team.

- The presented quenched analysis (Magnet Protection Considerations by Soren Prestemon) are based on the Wilson's QUENCH code with several simplifications: no mutual inductance with other coils, quench does not propagate to other coils, no "quench back" taken into account. These simplifications could lead to incorrect results. Examples: the currents shown in page 9 would have a different behaviour if the mutual inductances are taken into account; the hot-spot temperatures shown in page 10 are correct only for the quenched coil. In fact, analyses done by V.Kashikhin showed that, as consequence of the magnetic coupling, coils that are not yet quenched could have to stand currents as high as 320 A.
- Some parts, and scenarios of quench protection system work were not yet not analyzed

5.2 Comments on the electric circuit used during the tests

There are criticisms about the circuit used for testing the magnet.

- It appears that the magnets were powered in series during the tests. In case of resistive transition of one specific coil, individually protected by a cold diode with a resistor in parallel, the shunt resistor could be totally overheated in the quenched coil only; thus during the quench time, the current is flowing through the current leads. This is not the condition for which the magnet and system were designed to operate. In addition the real quench scenarios are not fully understood.
- The total inductance with all coils in series is 110 H. The resistance of 6 protecting resistors is 0.12 Ohm. Cold diodes opening voltage is 4-6 V. So, the allowable voltage on the rapid discharge resistor is 20-30 V. At a current of 275 A, the external discharge resistance should be less than 0.073- 0.11 Ohm. In this case the discharge time constant is 1000-1500 s.

  At such large time constants the "rapid" discharge system could not be used as the component of really fast active quench protection system to protect HTS and cold leads.

- After looking at MICE-note 324, the committee was very surprised to see that after disassembling the magnet a further problem had been discovered: overheating of the protecting cold resistors had burned the G10 protection sheath (as shown in fig.10 of the report). Looking at that fig.10 one can see that the resistors (the 6 of them protecting individual coils) went very close to melt themselves. <u>The committee regrets that this accident was not clearly presented by the SS team. The electrical circuit and the protection system appears more and more the most critical issue of this magnet and would require a deeper analysis.</u> From a later information given by S.Virostek (after consulting Wang MNR), it appears that the resistors, which are made of stainless steel, were expected (by Wang NMR) to heat up due to resistive heating occurring during a quench. Wang NMR does not think that the overheating was due to the power supply remaining on after the quench (as written in the note 324); since the power supply was always switched off manually as soon as the quench began. According to Wang NMR, the surrounding material that looked like resulting from melting of the resistors was made of remnants of the epoxy from the burned G10, while the stainless steel was not in danger of melting. Wang NMR checked the structural integrity of the resistors and the solder joints at their ends and found them to be fine. Their opinion is that the resistors have survived about 10 quenches, so there is no reason to modify them at this point and that the observed heating is normal. The only issue was the charring of the G10 sheet which was touching the resistors. The vendor fix is to replace the G10 with a woven fiber-glass cloth that can withstand higher temperatures. <u>The review committee totally disagrees with this approach</u>.

<u>5.3 Comments on the current leads protection</u>

- The part of the electrical circuit that extends from the bottom end of the HTS leads to the LTS leads in the helium bath is very critical. The LTS leads transfer the current in vacuum environment through a vacuum-to-liquid-helium leak-tight feed-through. The temperature of the LTS leads depends on the heat conducted by the HTS leads themselves, i.e. it depends on the temperature of the upper stage of the cryo-cooler, on the joint resistances and on the liquid helium level in the cryostat.
- In view of an active protection of the HTS leads, it shall be taken into account that the temperature sensor TPR03, being located at some position on the copper plate, is not indicative of the specific temperature at the warm end of each lead. As such, it cannot be used as signal for safe protection of the leads. Since no temperatures sensors are available at the warm end of each lead, it follows that, during the past magnet tests, there was no information available on the specific aspect of the performance of thermalization of the top part of the HTS lead against the upper stage of the cryo-cooler. It is not clear from the pictures how the electrical insulation of each lead against the upper stage of the cryo-cooler is performed.

5.4 Recommendations for quench issues

The review committee recommends:

- to continue the analysis of the quench protection system, including Coupled transient magnetic and thermal calculations, eddy currents in the Aluminium mandrel, external circuits with shunt resistors.
- Investigation of different quench scenarios and definition of the hotspot temperatures of coils, leads and shunts.
- Definition of peak voltages: to ground, and layer to layer.
- Definition of the optimal shunt resistor values for all coils to reduce risk.
- Definition of the allowable peak operating current to eliminate the risk of coil damage.
- Measurement of the leakage current to ground for each coil, to check the status of electrical insulation.
- Limitation of the test current to 200 A until all points above are verified and understood.
- Design of the magnet test procedure ensuring a minimal risk of cold mass damage.

5.5 Recommendations for current leads

- The HTS leads and corresponding LTS leads bus shall be protected by an active system (monitoring does not serve for protection). Both resistive and HTS leads shall be separately protected at different voltage threshold – about 100 mV for the resistive part and 1 mV for the HTS part. Of course any active protection will be insufficient for protection of the HTS part of the lead if the time constant of the circuit is too long (> 1000 s). The need to protect the leads implies a revision of the electrical circuit feeding the coils with current.
- Before a new run of the system, the question of the resistive heating in the HTS leads shall be fully understood (MICE Note 292). This could be due to problems associated with the HTS element itself, which would then appear again during the operation of the repaired system. The test of each HTS units in liquid nitrogen would be a simple way to verify the integrity of the components, which should be exchanged if needed.
- It should be verified that the LTS connection contains enough cross section of stabilizer to enable operation below Tc in the worst (higher heat load) condition. Since there is no instrumentation available, this aspect of the design could not be verified during the previous tests

- Powering shall be possible only if the temperature of the upper stage of the cryo-cooler and the liquid helium level are within specified values (***cryo-OK signal***). During powering, the loss of the cryo-OK shall generate a power abort.
- The SS team is invited to implement thermometers on the feed-through top flange where the wires enter the cold mass. The information given by the thermometry in this particular location is necessary to verify that the repair has been successful and is adequate for normal operation.

5.6 Recommendations for the electrical circuit.

- The electrical circuit shall be revised with the aim to protect the leads. There are different possibilities which shall be studied and decided in the more general frame of the whole MICE system also including other magnets.
- It is warmly recommended to study in much more detail the current flowing in the overheated protecting resistors before applying the fix proposed by the vendor (which in fact is a no-fix). The SS team shall consider increasing the mass of the cold resistors.

6. Heat load at 4.2 K

6.1 Comment about the measured heat load at 4.2K

- The measured heat load to cold mass at 4.2K is discussed in the note 292. "What Happened with Spectrometer Magnet 2B". In fact the excess heat loads were measured with three different methods. The most reliable number seems to be 1.55 W measured through the gas evaporation. This number is anyway affected by some error because only the latent heat is considered. If the cold gas is leaving the cold mass at 5K or 5.2 K (this can not excluded looking at the thermometer readings) the heat load has not only caused the LHe to evaporate but also the gas He to warm up to 5-5.2K. Considering the enthalpy variation of He at atmospheric pressure between 5.2 K and 4.2 K (~7000J/kg), one finds that the heat load causing the measured evaporation is 30% higher (2.05 W).
- Since one should like to compare the total effective heat load with models and computations, it is needed to have in hand a measured value of the total heat load. In order to get this number one has to speculate about the real cooling power at 4.2K. The temperatures of the second stages TSD6, TSD7 and TSD8 were not logged but, apparently, only measured from time to time. According to note 292, they are in the range 4.3 K-4.9K. At the same time the first stages (TPR14, TPR15 and TPR16 also not available) were at temperatures of 42.7 K - 44 K. In these conditions the presumed

cooling power can range between 1.5W to 2.5 W. Assuming an average of 2W per cryo-head, the total cooling power at 4.2K would be 6W. The excess heat load (causing boil-off) shall be summed to this number giving 8 W, which seems a more cautious evaluation of the real heat load at 4.2K (wrt 7 W declared by SS team).

6,2 Comment about the calculated heat load at 4.2K

According the presented "Heat leak calculations" by Tapio Niinikoski, the total heat load contributions at 4.2 K sums to 6.0 W (2 W less than the experimental indication according the evaluation of review committee). The committee has some reserves on this computation:

- The direct shine from 300K to 4.2 K is evaluated 1W. This estimation seems based on the preliminary analyses done by Bob Sanders during the review of spring 2010. In fact the basic information (how good the copper foil is thermally anchored to the shield) was not clear; Bob gave a range of loads from 0.1 W to 1.0 W. The 1.0 W number could be too high.
- The value of 0.4 W for the resistive joints in the cold mass appears too high and not justified.
- It is possible that a bad vacuum gives a substantial contribution to the heat load at 4.2 K. It is suspected that the most likely vacuum problem with the magnet 2B test was not helium gas but out-gassing of air and water from S2 fiber-glass, G10, wire insulation, metal surfaces and MLI. The preferred practice is to connect a large capacity vacuum pump to the vacuum jacket and pump for several days. That wasn't done for the magnet 2B test. In Tapio's computation the contribution of residual gas is assumed to be negligible (just because no information was available).
- Chapter 3 of the Wang NMR design report listed the thermal conductivity integral of the S2 fiber-glass from 80K to 4.2K as 0.0926 W/cm. That number is about 1/2 of that of G10 and of the available information on S2 fiber-glass. The Wang NMR thermal conductivity integral is not credible. The Wang NMR design report ignored the thermal resistance of the copper strap connecting the cold mass support intercept to the shield. Independent calculations made in Fermilab by both Zhijing Tang and Bob Sanders confirm that the strap raised the cold mass intercept temperature 8.5K during the 2B test. It was obvious, from statements made by them when answering the review committee questions on the subject of the cold mass supports, that the LBNL team has still not in earnest reviewed or repeated the calculations that appear in the thermal design documents of the Wang NMR design report.

6.3 Comment about the evaluated heat load at 4.2K after repair

- The evaluation of ~3W for the heat load at 4.2 K predicted after applying the proposed fixes is based on the calculated contributions to heat loads and the effects of the fixes on these contributions. This approach is not taking into account the possible over and under estimations of the various contributions (as explained in section 6.2) and does not allow for the fact that up to 2 W are missing. On this basis it is very difficult to give a firm opinion on the expected heat load at 4.2 K. There is the feeling that it should be lower than in test 2B by 1-2 Watt and that, consequently, upgrade to five 2-stage cryo-coolers should solve the problem and reduce the boil-off to zero. Unfortunately this is not a solid technical statement. The review committee thinks that this project suffers from a lack of solid thermal engineering calculations using calculators, spreadsheets or FEA that reference real engineering drawings. Specific thermal calculations should be specified and reviewed by people outside LBNL. During the 2009 review it seemed that there was an attempt to attach the problem through a FE analysis on a detailed thermal model (F. Trillaud was working on this). Now it appears that this approach has been abandoned.

7. Heat load to the shield and I stage of cryo-coolers

7.1 Comment about the temperatures of the I stages and thermal shield

For what regards the heat load to the first stage and to the shield, the test 2B suffered the same problems as test 2A:

a) High temperature gradient (ΔT=40 K) between the copper plate (which is thermally anchored to the first stages) and the shield
b) High available cooling power at the first stages (277W) but evaluated heat loads apparently not higher than 100 W.

Problem a) was well known and understood during the review of November 2009: the cooling of the shield was, and still is, limited by the high thermal impedance between copper plate and shield. The thermal contact between copper plate and shield shall be improved and SS team knows this necessity since one year!

Problem b) is still puzzling three review committees members. The analysis of the logged temperature data for thermometers TPR04 (on copper plate in proximity of 2-stage Cryo-cooler farther from current leads), TPR06 (on copper plate in proximity of 2-stage Cryo-cooler closer to current leads) and TPR03 (on copper plate in proximity of single stage cryo-cooler) shows two things:

i) There is an apparent temperature gradient (5 K in total): the temperature of the copper plate is progressively lower moving towards the single stage temperature.

ii) Steady state conditions were never achieved (temperatures are still decreasing with time in the logged data).

The committee suspects that the 2-stage cryo-coolers are not able to transfer their potential cooling power to the copper plate because the thermal contact between the first stages and copper plate is done through a mechanical contact involving a tapered element covered by conductive grease (see presentation of Mike Green at the 2009 in-person review, http://indico.cern.ch/conferenceDisplay.py?confId=69031). The data regarding the direct measurements of the first stage temperature (from 42.7K to 44 K) do not seem to confirm this supposition. A bad contact of the tapered element would cause these temperatures to be lower (if we have no contact at all the temperature should be 31.5 k). On the other hand, these temperature were not monitored, so it is not clear whether steady state conditions were really achieved, and it is not known how precise the thermometers were. As of matter of facts there is a real possibility that these contacts are weakened or loosed due to the differential thermal contractions of many elements (cryo-coolers main body, sleeves containing the cryo-coolers, the G10 rods supporting the copper plate, the shield attached to the copper plate through Al alloy connections,..). In synthesis: the committee cannot exclude that the thermal load is higher than evaluated and that at the same time the real available cooling power is much less than believed.

7.2 Recommendations

- Repeat all shield heat load calculations without relying on Wang NMR reports or calculations. Do not use thermal conductivity integrals or thermal conductivity data from Wang NMR. Use thermal conductivity data from the literature for S2 fiber-glass and G10. If needed use G10 properties for S2 fiber-glass. In the calculations include the effect of radiation on the cold mass supports. Review all drawings and include all possible heat loads in the calculations. For example include the G10 thermal bumpers on drawing # MICE-6600.
- Complete the engineering drawings for the changes being made to the shield. By calculations that refer to the drawings and the above heat load calculations, determine the shield temperature in critical locations such as the bore and the cold mass support intercepts. It is highly desirable to keep the entire shield, including the cold mass support intercepts below 70K. Include the thermal resistance of the copper strap in determining the temperature of the cold mass support shield intercept.

- Determine the affect of thermal contractions on the tapered contact between the cryo-cooler 1st stages and the copper plate. Include the forces exerted by the main aluminum shield on the copper plate. By calculation determine the thermal resistance of the gap. There might be natural convection in the gap. Make design changes if the thermal resistance is too large.
- Compare the exact physical location of the thermometry used to measure the cryo-cooler 1st stage temperature to the exact location of thermometry the manufacturer uses to measure cryo-cooler performance. For example Cryomech on a AL300 measures the cold head temperature on the upper side of the cold head during a performance test.
- The accuracy (and position) of thermometry used to measure cryo-cooler 1st stage temperature is critical in evaluating cryo-cooler performance. Is the accuracy of the thermometry sufficient? Determine if heat conduction through the wires or radiation heat loads affect the accuracy.

8. Comments to repair plan

The review committee comments on the repair plan, based on the findings of sections 5, 6 and 7.

The SS team correctly based the repair plan on a list of Magnet Analyses before implementing a Design Modification Plan involving: a) 4.2K heat load reduction, b) Radiation shield improvement, c) Other key improvements.

Regarding the analyses under way the committee comments are:

1) A complete set of the latest as-built drawings is still being compiled, so the analysis do not, as yet, have a strong basis

2) As reported in section 6 the thermal analysis, even if much more detailed and careful than was previously done, is still not providing clear and un-doubtful information

3) The EM calculations, redone for testing and operation, are consisting in some quench analyses but still require work for analyzing the possible quench scenarios (see section 4). The committee found many critical issues related to the protection of the current leads (all current leads: normal conducting leads, HTS leads and cold lead), which shall be studied in a more general revision of the electrical circuit used for feeding the coils, both at the vendor and in the final situation at RAL.

4) The instrumentation plan is being modified, but, to date, no information has been received to indicate that there are any plans to improve the instrumentation surrounding the HTS and LTS leads and their heat-intercepts. This is an area that has been found to be troublesome, and existing instrumentation is inadequate for monitoring & control, as well as potential future diagnostics. A similar issue exists

regarding the monitoring and control of the insulating vacuum and its pumping system, although this issue is being addressed.
5) The reassessment of the mechanical support of the magnet, leads, piping and of the internal components is a good idea. The committee had no elements for giving an opinion on this aspect.

<u>For what regards the Design Modification Plan</u> (done in parallel to the analysis effort) , the SS team is developing a modification and assembly plan including: a) reduction of heat leaks to the cold mass, b) the addition of more cryo cooling power, c) modification of the cold leads near the feeds-through to prevent burn-out. The committee notes that this plan does not include any action related to active lead protection. Only a passive protection and only of the cold lead has been planned. Regarding the proposed actions the committee opinions are:
1) The activity toward the improvement of vacuum pumping and instrumentation looks fine
2) All actions for limiting the heat loads to 4.2 K are reasonable (covering of the all 4.2 K areas with actively cooled shield where possible, baffles to the vent, improvement of MLI on cold mass bore, addressing of thermal acoustic oscillations problem, optimization of sensor wires with proper heat sinks)
3) The improvement of thermal conductivity of the shield with copper and pure aluminum is important and shall surely be done
4) The improvement of the thermal connection between the cooler first stage and the radiation shield is extremely important and necessary. The SS teams intends replacing the previous aluminum banding with flexible copper sheets. No details were provided, so it is not possible to give a technical opinion. The committee recommends implementing this improvement after the analyses suggested in section 7.
5) The same considerations apply to the actions finalized to reduce the heat loads from a series of components (shield pass through holes for the cold mass supports, intermediate cold mass support heat intercepts, and shielding of the warm end of the supports). The committee recommends particular care in the area of the supports. For preventing shine from 300K to 70K and from 70K to 4K, it is suggested using shine stoppers mounted off the 70K centre part of the supports. Simple copper plate riveted together to surround the support section can be made with clearances in a way that does not generate a pumping impedance.
6) As discussed in section 6.3, increasing the cooling power by using five 2-stage pulsed tube coolers and one single-stage cooler is based on a fair but not excellent understanding of the heat loads mechanisms at 4.2K. It appears that the choice to add two 2-stage cryo-coolers is a ‘brute force solution’ mainly based on the measured LHe boil-off and on the hope to reduce as possible the heat loads through the actions

as above point 2,3,4 and 5. Given the present knowledge of the heat loads, the five+one cryo-cooler system appears complex and probably highly redundant, but the committee cannot exclude that, on the opposite, it could turn out to be barely sufficient for avoiding LHe boil-off.

7) The elimination of the LN reservoir seems reasonable. In a complex and not completely understood system, this redundant component can generate problems (such as to contribute to weakening the thermal contact of the tapered component inside the first stage)

8) The proposed improvement of the thermal/mechanical stabilities of the cold leads by adding extra copper/superconductor near the cold mass feeds-through looks fine. The committee suggests to take a larger margin if possible (adding even more copper).This is one of the most critical areas. As stressed before (see section 5.5), there should be adequate thermometry and voltage taps for controlling that the temperatures are in the correct range and that no overheating takes place.

This modification plan shall integrate actions regarding:

1) The modification of the electrical circuit to allow implementation of active protection of the HTS and LTS current leads.

2) The active protection of all leads involving voltage taps and suitable thermometry,

9. Manpower

Eight persons are committed to the repair task for a total FTE of 2.45. The ratio FTE/persons denotes an excessive and not recommendable subdivision of the work. However it is recognized that the project is followed much more consistently than in the past. As correctly stressed by Steve Virostek, *it is important to have the appropriate knowledgeable and experienced individuals on site during the critical operations*. At present it seems that this task cannot be fulfilled 100%. The review committee thinks that a continuous and well coordinated follow-up of all operations at the vendor is fundamental for the success of the repair plan. The review committee thinks that many times in the past the information flow between the vendor and the SS team was insufficient and lacking important details.

10. Schedule and next actions

The review committee did not go in the details of the schedule. The reason is that, as discussed in above sections, the modification plan needs more thought and analysis before it can start. In particular the review committee stresses the importance to study implementation of an effective protection for all the leads, and of adequate thermometry for controlling the whole system.

11. Conclusions

The Review Committee expresses appreciation for the attitude of the SS team in its efforts to understand in a deeper way the problems encountered in the fabrication and operation of the spectrometer solenoids. The resources have been increased by the addition of highly competent, but unfortunately part-time, staff. Previous areas of weakness are being reinforced, but follow-up at the vendor should continue to increase. The Review Committee encourages the SS team to continue in this direction and recommends intensification of the additional project staff deployment.

On the basis of the analysis done by the Review Committee, the SS team is advised not to move towards the present repair plan, but rather finish the analyses, as recommended in sections 5, 6 and 7, including new facts (overheating of cold protection resistors). The implementation of an effective active protection of the leads must be studied, together with the resulting modifications to the electrical circuit.