02/09/03

MUTAC Committee Report on the Muon Collaboration Review January 14-15, 2003

Charge to MUTAC for the January 14–15 Committee Meeting

The Advisory Committee is to:
1) Review and comment on the R&D progress achieved during the last year.
2) Review and give advice on the R&D plans and corresponding budgets for fiscal year 2003, as well as on the long-range R&D directions.
3) Assess and give advice on plans for the international Muon Ionization Cooling Experiment (MICE), and comment on the relationship between MUCOOL and MICE.
4) Assess and give advice on plans for the Targetry program.
5) Assess the status of the beam simulation effort, especially that aimed at 6D cooling scenarios (e.g., cooling rings).
6) Evaluate both the NSF-sponsored and the ICAR-sponsored muon activities and comment on how each fits into the overall MC R&D program.

It is expected that the MUTAC will convey their summary views and recommendations orally to the Muon Collider Oversight Group (MCOG) and to the MC at the closeout session of the review, and in written form as a report to be submitted to the MCOG within one month following the review meeting.

MUTAC Report 2003 Summary Response to Charge

1) Review and comment on the R&D progress achieved during the last year

The committee notes with pleasure the enthusiasm evident at the MUTAC Review, and the refreshing ideas and progress made over the past year. This is particularly noteworthy since this progress has been made in the face of very difficult funding conditions.

The recent successes of the neutrino oscillation experiments have solved the solar neutrino puzzle and convincingly demonstrated that neutrinos are massive. In order to explore leptonic CP-violation and precisely measure "enlarged" Standard Model parameters, a new facility is necessary. A neutrino factory based on a muon storage ring with the proposed muon-beam intensity and energy is the best facility that we currently know of to achieve these physics goals. It is likely that Superbeam neutrino facilities will be built, and the case for the muon storage rings should be considered in that context.

Of particular note in the Muon Collaboration (MC) activities are the new phase rotation, ring cooler, and acceleration system studies, that may lead to a rather different overall layout of a neutrino factory for a future Study 3 (as compared with Studies 1 and 2) and may provide considerable cost reduction.

Also of special note is the development of an experimental proposal for a Muon Ionization Cooling Experiment (MICE) organized in an international framework. The US MUCOOL effort would develop hardware and do systems integration for the cooling channel of MICE. MUCOOL, the hardware development effort, appears to interface well with MICE, the actual experiment.

The committee agrees that first priority within MC must be given to the cooling channel engineering development leading to a proof of principle.

The liquid hydrogen absorber effort proceeds well under the guidance of ICAR. ICAR itself is an example of positive and productive university based collaboration in accelerator R&D.

Construction of the Test Area at the end of the Fermilab Linac has started and will provide infrastructure for the demonstration of the engineering feasibility of the cooling channel hardware.

The normal conducting cavity testing has proceeded with tests of an 800 MHz pillbox cavity with copper windows, in a solenoidal field. To date these tests have shown evidence of window pitting related to breakdown of the cavity in the magnetic field. Finding a solution to this problem is the most critical task for MUCOOL for the near future.

2) Review and give advice on the R&D plans and corresponding budgets for fiscal year 2003, as well as on the long-range R&D directions

MC hardware activities in 03 and beyond are funding limited. This is apparent in the fabrication schedule of a 200MHz cooling system cavity (the area of highest priority) and in the Hg jet target program that needs to integrate tests of a target in a solenoid with high intensity beam.

An additional ~$1M would make a considerable difference to the time scale on which a 200 MHz cavity could reach the testing stage. Substantial additional funds would be required to implement a realistic target test in a solenoid.

The schedule calls for the initiation of an end to end neutrino factory feasibility "Study 3" in 2005. The committee encourages this goal as a number of new design ideas may make for a simpler, more realistic, and less expensive design.

The schedule outlined for MUCOOL must connect with the planned initiation of the MICE experiment. A four-cavity module assembly for MICE is scheduled for end of Q3 2006. The committee is skeptical about the time scale given to perform the prototyping and testing of the components in the Fermilab Test Area prior to fabrication of hardware for MICE. The time needed for engineering development and testing prior to proceeding with fabrication for MICE seems unrealistically short, with completion of the MUCOOL hardware development phase by end of Q3 2004. We suggest a reevaluation of this proposed schedule, especially as the funding situation develops and as more is known about the cavity performance.

As noted above, proof of adequate cavity performance in a solenoid field is key to the present cooling concept. Further tests on 800 MHz structures are absolutely necessary. Though the 800 MHz testing may not uncover all the difficulties to be encountered at 200 MHz, success here is probably a requirement for success at 200 MHz. There is of course the issue of beginning fabrication of the 200 MHz cavities without a clear understanding of the solutions at 800 MHz. The 200 MHz cavities will be much more difficult to deal with and thought has been given initially to how window modifications will be carried out. Flexibility should be preserved where it is possible. The full test set up must include a large solenoid, a rather large budget item, in order to test fully the performance and operational characteristics of the cavity.

3) Assess and give advice on plans for the international Muon Ionization Cooling Experiment (MICE), and comment on the relationship between MUCOOL and MICE

The committee is very pleased to see the development of the MICE proposal, as we believe ionization cooling is a fundamental part of the neutrino factory accelerator design that must be demonstrated. The international character of the MICE experiment is also very encouraging.

The committee is pleased to see that the proposal has been submitted to a laboratory (Rutherford Lab, ISIS) that has much of the needed infrastructure and potential for easy beamline modification to supply muons, as well as experience with liquid hydrogen safety. With the recent reemergence of UK interest in accelerator physics, this proposal appears to be a very positive development. We hope for acceptance of the plan by the laboratory in the near future.

The MICE plan appears to be well thought out. The design of the experimental detector, along with the planned phases of testing and commissioning of the detector prior to installation of the cooling channel, seem to make good sense.

Here again the overall schedule may be optimistic and is certainly hostage to obtaining commitment from different funding agencies internationally. Overall the experiment is estimated at $25M plus 176 FTE over 4 years beginning in 2004. The full experiment with two cavities and 3 absorbers would begin in 2007. We note the US MUCOOL collaboration has submitted a proposal to NSF for its part of the MICE effort. We encourage NSF to review it in a timely manner.

There appears to be excellent coordination between MUCOOL and MICE. This is strengthened by the dual role Kaplan plays in both collaborations. MUCOOL has the mission of developing and testing the hardware for the cooling channel and incorporating and testing hardware developed by others (e.g. KEK absorbers). MICE has the responsibility for the experiment (both the cooling channel, built from experience gained at MUCOOL, and the detector), and the beamline. The organizational division between MUCOOL and MICE seems logical and well thought out.

4) Assess and give advice on plans for the Targetry program

Experiments on Hg jet targetry have been carried out a) with beam ($4x10^{12}$) but without a solenoidal field, at BNL E951, and b) with a solenoidal field, but without beam at CERN. Photographs have been taken of the development of the jet in both cases. With beam, non-explosive disruption of the jet is observed, but at a beam charge a factor of 4 below that assumed in Feasibility Study 2, and below the boiling threshold. Measurements of the jet with the solenoid clearly show the stabilizing effect of the magnetic field in the 10-20 T range. These are very encouraging observations which strengthen the design base.

A simulation program is under development by R. Samulyak. The program takes into account detailed data on material equation of state, and magnetohydrodynamic properties. The results of the simulation are most impressive and beautifully illustrate the development of the interaction of the jet in a solenoid field with a beam. Further improvements to the code are necessary to incorporate higher beam charge and to allow for phase transitions (cavitation). This appears to be a very fine piece of work and every encouragement should be given for further development of the simulation and application to the expected target parameters especially above the two phase region and with impurities. Experimental benchmarking of the code from existing data is underway, and further comparison will be of great interest when the BNL target system is available.

A plan for construction and test of a target system at BNL with a solenoid, power supply, and beam has been developed. The most recent variant of this system with a new higher-voltage power supply, no use of liquid hydrogen cryogen cooling, and with 15T field (instead of 20T) seems the most promising. However, the solenoid, power supply and cryogenic system is estimated at $1.9M and should still take second priority to the cooling development program.

5) Assess the status of the beam simulation effort, especially that aimed at 6D cooling scenarios (e.g., cooling rings)

The committee heard talks related to on-going simulation work on neutrino factories. The possibility of a very different overall design than that presented in Studies 1 and 2 is emerging. Two efforts are of especial note.

D. Neuffer has developed a scheme of muon rf capture, bunching, phase rotation, and momentum correction that replaces the induction linac scheme of studies 1 and 2. This is a major design improvement and should significantly simplify the rf capture design and may significantly reduce cost and complexity if major difficulties are not encountered in the process of integrating it into the entire scheme. This option will need to be matched into the cooling system, and an engineering design will need to be developed as rapidly as practical.

Ring cooler design efforts show great promise as well. Simulations show similar transmission and transverse emittance, and reduced longitudinal emittance, when compared to the Study 2 single pass cooling channel. The circumference of the ring is potentially about 1/3 the length of the Study 2 channel, and this may result in significant savings. In order for one of these designs to replace the Study 2 channel, investigations must be carried out on injection/extraction scenarios, on fast kicker development, and on the limits of absorber heating from multiple beam traversals.

FFAG designs are being considered as alternatives to RLA's for acceleration. Here again more work is necessary to determine the relative benefits. Injection /extraction systems, and the match between linac and arc sections, have not been designed and need to be carried out prior to the start of Study 3.

Overall, the accelerator design and simulation work shows great promise and the emergence of many new ideas. Further work is clearly called for in order to make choices prior to starting an integrated Study 3. The committee looks forward to further progress over the next year. Additional work, especially on the ring cooling issues, should better clarify their potential.

6) Evaluate both the NSF-sponsored and the ICAR-sponsored muon activities and comment on how each fits into the overall MC R&D program.

The Cornell program

The NSF sponsors the Cornell 200 MHz superconducting cavity prototype testing program. This R&D, though not related to the cooling experiment, is critical to establish achievable parameters for the recirculating linac. Recent work on FFAG design indicates that detailed engineering comparison between warm and superconducting rf will need to be carried out as FFAG designs mature.

The Cornell work, in collaboration with CERN, on the 200MHz single cell Nb sputtered on Cu cavity, has had very encouraging results over the last year. After a second attempt at high pressure rinsing and coupler installation at CERN the cavity reached 11MV/m at a Q of 0.7×10^9 before being limited by the available power in the test setup. The design field of Study 2 is 15-18MV/m.

This cavity, like other sputtered cavities shows a deterioration of Q as the gradient increases (Q slope). The Cornell group plans to investigate the surface properties associated with this phenomenon. This is a subject of general interest in the SRF community as all would benefit from a better understanding of the surface physics. The development of high Q, high gradient sputtered cavities could substantially reduce costs compared with solid Nb cavities. To this end we also encourage investigation of other techniques of deposition of Nb on Cu.

Through Cornell, the NSF also sponsors a number of small university activities. Among these are the frictional cooling experiment, absorber studies, cooling theory and simulation, studies of radiation damage, and studies of pulsed acceleration schemes. The present grant is for 3 years and ends in 04. Cornell does not wish to continue contract management of these small grants, but does wish to continue the cavity R&D.

The Illinois Consortium for Accelerator Research (ICAR) program

ICAR is a collaboration of five Illinois universities with funds from the State of Illinois. The collaboration has a large number of students and postdocs in the MUCOOL activity and is clearly a successful example of university cooperation with national labs on future accelerator R&D. ICAR involvement in MUCOOL through the absorber development is a part of the highest priority effort of the collaboration i.e. realization of a cooling proof of principle experiment. ICAR appears to work seamlessly with MUCOOL and MICE.

ICAR is focusing its efforts on the liquid hydrogen absorbers. Emphasis over the last year has been on absorber window design, measurement and testing, as well as on developing a basic understanding of the safety requirements. The work on the windows continues to be high class, and illustrates how university involvement in accelerator R&D can be a very positive experience. Window design and thickness have improved. Measurements of the window shape and breaking pressure have been carried out and agree well with calculated expectations. It is reassuring to note the present interest in the 2000 series Al-Li “super” alloys which have excellent cryogenic properties and do not become glass like at low temperature. This material may possibly become the material of engineering choice for these high stress thin windows because of its desirable properties of ductility and strength at low temperature. A calculation needs to be done on the effects of a solenoid quench on the windows.

Work on the safety requirements has uncovered the necessity for engineering changes. In order to cover all conceivable failure situations, a second or even a third window per absorber end will be needed. The committee agrees with MUCOOL that building to real engineering requirements is key to having the development proceed along realistic lines. Real systems tests as planned by ICAR at the Fermilab Test Area, with integrated instrumentation control and data retrieval, are key to the realization of a MICE demonstration. The committee also notes that interaction with the MICE experiment has already brought in the necessity for incorporation of safety requirements and experience basis from more than one lab (i.e., FNAL and Rutherford).

We understand that the Illinois grant is for 3-5years. It will be critical that it is renewed so that the work and university involvement can continue toward realization of the MICE experiment.

Concluding Remarks to Charge

Overall, MUTAC was impressed by the accomplishments since the last meeting, particularly given the strained financial situation. MUTAC can enthusiastically assure

MCOG that the limited funding is being well and carefully utilized. Present funding is substantially below the ~$8M level endorsed by the HEPAP Report. Additional funding would certainly be helpful in the implementation of the 200 MHz warm rf tests. However, the committee cannot make rational recommendations for increments at a time of total HEP funding limitations without knowing the impact on other HEP programs. We do however note that the Muon Collaboration is a fine example of laboratory -university collaboration on accelerator R&D. It also illustrates the need for increased accelerator R&D funding across the fields of HEP, NP, and BES.

Further comments on the MUTAC 03 Review

1) Theory and Simulation

The committee heard 5 talks related to ongoing simulation work on neutrino factories. What is emerging is the possibility of a very different design than that presented in Studies 1 and 2.

Raja gave an overview of the organization and studies of the theory and simulation group. D. Neuffer presented a new scheme for the phase rotation section, i.e., bunching the muon beam before phase rotation. This enables the replacement of the expensive induction linacs with resonant cavities. R. Palmer summarized the progress in the study of ring coolers, putting emphasis on the RFOFO scheme. S. Berg gave a summary of the accelerators, including a multiple-arc recirculator and an FFAG. In particular, the latter showed significant progress. D. Summers discussed the possibility of using pulsed magnets for acceleration in a rapid cycling synchrotron. R. Samulyak presented simulation results of the targetry.

The committee was very favorably impressed by the progress in the design scenario evaluations.

First, the proposed bunching scheme achieves considerable progress in cost reduction without degrading performance. The required rf frequency, 200 to 300MHz, is high compared with the unrealistic frequency which would be needed without the bunching-before-rotation method, but is still quite low in comparison with the present technology of low-frequency high-gradient cavities. Development of such cavities is indispensable. However, this is more or less common to other sections, such as the cooling section. The new scheme requires cavities of more than 10 different frequencies with specific phase relations. This can presumably be done. The design is still in the initial stage. Further simulations have to be done to optimize for higher muon rate. For overall optimization and for the end-to-end simulation, it is desirable to design the matching section as soon as possible. Further work is required to develop an engineered solution. This scheme seems much preferable to the induction linac in both technical difficulty and potential cost. This idea appears to be a major breakthrough.

Second, the committee also saw remarkable progress in the ring cooler design. Results show that in principle cooling rings provide similar or better transmission and emittance than a long cooling channel. Here again cost savings could be substantial as the length involved would be ~30% of a channel. Among all the schemes, the RFOFO looks the most practical. The injection scheme requires further study, but the RFOFO seems better than other ring cooling schemes from this point of view also. For all the ring cooler designs, the injection/extraction systems are the most urgent problems. Also, just how much beam heating the absorbers can be designed for must be evaluated. Design comparisons between ring cooler options should include these systems.

Third, FFAG designs have begun to be considered. There has been remarkable progress in understanding FFAG designs in the last year. FFAG designs now show wider possibilities than before, with the inclusion of non-scaled FFAG and racetrack types. Development of a computer tracking code which is capable of treating extremely large energy spreads and changes, with realistic magnetic fields and large energy gain in the acceleration sections, is indispensable. Given the novel character of the FFAG design, it may be advisable to build a low energy FFAG test machine.

In the simulation of ring coolers and acceleration systems, the possible machine errors should be included.

The committee heard an additional report on the pulsed acceleration scheme. This idea seems further from real application.

2a) Warm RF & Mucool

MUCOOL

The MUCOOL effort is a key ingredient in the R&D towards a neutrino factory. The highest priority of the hardware development of the MC R&D program is the development and prototyping and testing of the cooling channel components. The two main components are the normal conducting 200 MHz cavities which must be shown to operate in a 2T solenoidal field and the liquid hydrogen absorbers, which must have thin windows to the beam, must have sufficient cooling to deal with the beam heating, and must meet critical safety requirements.

The committee heard an overview of MUCOOL from Dan Kaplan of IIT, and the plans for integration of MUCOOL into the international Muon Ionization Cooling Experiment (MICE). Details of the work on normal-conducting RF were presented by Derun Li (LBNL) and Yagmur Torun (IIT).

805 MHz RF cavity tests

The test program of the 805 MHz RF cavity, at Lab G, has reached maturity and results are beginning to emerge. The open cell version of this cavity has been tested with, and without, a solenoidal field (2.5 T); an on-axis field of 23 MV/m was reached. Strong dark currents, and significant surface damage, were observed. A closed cell version was tested with both thick and thin copper windows during 2002. With thick copper windows, the cavity reached an on-axis field of 34 MV/m (without magnetic field). No damage, and little sparking, was seen. With a thin copper-window, the cavity was conditioned to 20 MV/m, then operated with field on. After many weeks of conditioning, the cavity reached 16 MV/m. Considerable multipacting, and high radiation, was observed. Improved performance was realized if the cavity was reconditioned without the field. On inspection, considerable pitting of the copper window, and copper dust at the bottom of window, were observed (although the cavity body and coupler were not damaged). Tests have recently started with TiN-coated beryllium windows. To date, without a field, the cavity has reached 16 MV/m with the TiN-coated beryllium windows. The tests of the TiN-coated beryllium windows in a magnetic field should yield important information toward resolving this issue.

Yagmur Torn of IIT described the issues related to dark current from the cavity. The dark current, if significant, can increase the heat load on the absorbers, compromise the window integrity, and produce radiation fields (primarily X-rays). These fields can lead to background that could interfere with the cavity diagnostics, and with the instrumentation to be used to make emittance measurements in MICE. Detailed measurements of the dark current over a range of about 14 orders of magnitude were carried out, using a variety of detectors. The results were extrapolated to the operating conditions expected for the 201 MHz cavities in the MICE, and indicated that the dark current backgrounds and the absorber heat loads should be tolerable.

Although the estimates of the background due to the dark currents are encouraging, the window pitting observed with the thin copper windows, and the observation of the copper dust, is cause for significant concern.

The cavity testing is the most critical part of this phase of the R&D program. It must be shown that the cavities can operate without breakdown at high gradient in a 2T solenoidal field. The testing effort at 800 MHz has the advantage of smaller size cavities and solenoid. However, so far rf operation in a magnetic field has not been promising. It is critical that work toward understanding and a successful solution of this problem on the 800 MHz cavities continue. This is clearly the highest priority challenge for the collaboration at this time.

201 MHz cavity

Construction and test of a 200 MHz cavity is some years away. A design for the 201 MHz cavity, which will be used in the MICE, has been completed, including a complete electromagnetic and thermal analysis. Grids, which are cheaper and provide less scattering, are being studied as alternatives to Be windows. Vendors are being identified for the cavity prototype. For operational testing with field in the cooling channel configuration, a solenoid ("coupling coil") will also be needed; this is currently planned for FY'05.

The committee is concerned first, that production of the prototype 200MHz cavity may start before the breakdown issues in the 800MHz cavity are understood and solved, and second that tests of the 201 MHz cavity with field will not be possible before FY'05. Although much can be learned by extrapolation from the 805 MHz tests, the bottom line will be the results with the 201 MHz cavity. RF cavity production for the MICE is scheduled to start in FY'05, even before the prototype cavities have been tested in a field. This seems to pose a significant risk. Efforts to move up the production of the complete coupling coil prototype and infrastructure, so that testing in a magnetic field can take place before FY'05, are encouraged but sound difficult. Complete testing, including quench tests, should be done with cavity, magnetic fields and absorbers prior to MICE production. Failing earlier 200 MHz tests, the start of cavity production for MICE should be delayed.

2b) Superconducting RF & NSF Sponsored research

The NSF is funding a number of muon collider/neutrino factory collaboration efforts, through a consortium grant administered by Cornell University. These activities, described in overview by Don Hartill of Cornell, include work on frictional cooling at Columbia University, absorber studies at IIT, NIU, and the University of Mississippi, cooling theory and simulation at the University of Chicago, UIUC, MSU, and UC Riverside, studies of radiation damage at MSU, studies of pulsed synchrotrons at the University of Mississippi, and, at Cornell, a program of development on 201 MHz superconducting RF cavities. The committee heard a detailed report on the RF work from Hasan Padamsee of Cornell.

The superconducting cavities will be fabricated using the technology of sputtered Nb films on copper, developed at CERN for the LEP cavities. The goal for the cavity development is a peak field of 25-30 MV/m (15-17 MV/m design accelerating field).

At Cornell, a facility has been constructed in which cavities can be tested in a vertical test setup. Initial tests of a single cell cavity fabricated at CERN showed multipacting at 3 MV/m, followed by field emission limited behavior at about 5 MV/m. After re-rinsing at CERN and high power processing, the same cavity reached an accelerating field of 10 MV/m, at a Q of 10^9. The cavity exhibited a Q-slope, which was probably not due to field emission. After further processing with helium for 20 hrs, the cavity reached its best accelerating field, 11 MV/m (corresponding to a peak field of about 19 MV/m).

The observed Q-slope is a general property of Nb-sputtered films, and is not present (to the same degree) with bulk Nb. This Q-slope has been seen in the LEP cavities. The Q slope is expected to be smaller at lower frequencies, and somewhat better performance had been expected at 201 MHz than was observed. The most likely route to better performance lies in improved Nb sputtering methods (or other deposition methods). Atomic Force Microscope studies of the cavity show large grains of Nb at the iris, which may be generating grain boundary losses. However, previous studies at CERN, on LEP cavities, had eliminated grain boundaries as a loss source.

Sputtering studies using bias will be continued in industry (at ACCEL), to try to improve the quality of the film. The use of krypton, instead of argon, for the sputtering gas, will be investigated. Studies of large scale cavity fabrication via spinning are also underway.

The committee was impressed with the progress of this effort: with the first prototype, a gradient of 75% of the design goal has been reached. However further progress may come more slowly, since the studies at CERN for the LEP cavities have already covered a great deal of ground in Nb-sputtered film development. Nevertheless, a fresh look at these issues by the Cornell group could provide a breakthrough in understanding. If the Cornell group attains the surface quality of the 350MHz LEP cavities and the performance gains expected at lower frequency an improvement of at least 5 in Q would be possible. If the performance of Nb-film cavities could be brought up to the level of that of bulk Nb, this would benefit not only the neutrino factory project, but also would be an enormous cost savings for any future accelerators based on superconducting RF.

3) ICAR

Absorbers

The design of the liquid hydrogen absorbers is being pursed at both IIT (funded through ICAR) and at KEK. The power handling capabilities may need to be as large as 10 kW, for cooling cells used in ring cooler designs, which is a considerable challenge, much larger than in conventional liquid hydrogen targets. Designs with windows as thin as possible are also very important as safety requirements demand a redundant set of windows for a containment vacuum around every absorber. Due to their superior cryogenic properties of ductility plus strength the use of the “super” Al-Li 2000 series alloys will be preferable for the windows. These alloys were developed to make cryogenic fuel vessels because of the glass transitions at low tempatures for standard Al alloys.

The committee is pleased at the significant role that university researchers are playing in the development of the absorbers. Designs that can handle up to 10 kW will be quite challenging.

Muon Test Area

The MUCOOL prototype hardware system tests will be carried out in an area being prepared at the end of the Fermilab linac, called the MUCOOL Test Area (MTA). This area will allow for integrated tests of the cooling systems: ncrf cavities, solenoids, and H2 absorbers. It will have both RF and Cryogenic infrastructure. In this area, a 400 MeV proton beam will be used to show that a cooling cell is operable in an intense beam. Beneficial occupancy of MTA is expected in the fall of this year, and, if funding permits, cryogenics and power will be installed in the area in FY’04. To complete preparations for the high-power beam test of MUCOOL, a solenoid will need to be fabricated for the 201 MHz cavity, a 400 MeV proton beamline from the linac will need to be implemented, and diagnostic instrumentation will need to be developed. Instrumentation development (for a CsI photodetetctor, a Cerenkov radiator, and a bolometric detector) is already underway, funded by ICAR, at UIUC and other universities.

The committee applauds the progress made in the development of the MUCOOL Test Area. This area is essential for the next stage of MUCOOL activities, leading to a demonstration of the prototype cooling unit's technical performance, a requirement for the MICE, and for a high power beam test of a cooling unit, which the MICE will not provide.

4) Mercury Jet Target

Simulations

Impressive numerical simulations of the behavior of the mercury jet target, when bombarded with a proton beam, are being carried out at BNL. R.Samulyak presented simulation results of the targetry. The models can currently reproduce the behavior of mercury jets in magnetic fields, and predict that the disruption of the jet due to the proton beam will be suppressed by the magnetic field. For improved predictions, the effects of cavitation produced by the beam must be properly included. Work is underway to include this in the model by using an isentropic equation of state for mercury, which can handle the effects of phase transitions. The model predictions will then be compared with the results of CERN and BNL target experiments as well as Sandia APEX experiments. The model will be used to simulate wave dynamics of the SNS target container.

The committee strongly supports this work, as a validated model of the jet behavior will be extremely useful in predicting target performance at neutrino factory parameters, which may not be experimentally accessible for some time.

Experiments

Targetry experiment at BNL (E951) has explored the disruption in a Hg jet by a beam of 4×10^{12} protons on target and found the disruption at this level to be nonexplosive over the relevant time scale. However it is to be noted that Study 2 specified 16×10^{12} protons, and that at the present beam level boiling does not take place whereas it would at the higher charge level. Jet observations at CERN with different solenoid magnetic field levels up to 20T clearly show suppression of sausaging of the jet as the field increases. Simulations clearly show stabilization of the jet with beam as the longitudinal magnetic field is increased.

The BNL Princeton Group has carried out a design (feasibility) study of just what it would take to carry out a beam test at BNL with a jet and a solenoid field. Major components requiring fabrication are the solenoid and its power supply. The initial study used liquid hydrogen as the cryogen and met with some safety objections. A more recent look makes it seem feasible to consider a larger power supply and a magnet cooling with liquid nitrogen at a field of 10-15T. Cost and schedule to proceed with this test are ~$1.9M and 3 years, exclusive of running of the AGS and its modification to allow higher charge investigations. The decision to use 15T field appears well justified and eases the magnet design and safety requirements considerably.

The MUTAC committee believes that the jet target is beginning to look feasible and that the experimental work on jets and separately with magnetic field show promise. The simulation studies and development should proceed with high priority. However the construction of an experiment with beam and magnetic field must take lower priority to developments associated with the MUCOOL R&D and prototyping for the MICE.

5) MUCOOL/MICE Integration

The MUCOOL activities (the building and testing of a prototype cooling cell, in a high-radiation environment) lead naturally into the MICE. MUCOOL is providing prototypes, testing, engineering integration, simulations, and development for the MICE. It is planned that the production cooling channel units, whose performance will be measured in the MICE, will also be provided by the MUCOOL team. A proposal to the NSF to fund these production units has just recently been submitted.

The committee feels that, for the most part, the MUCOOL/MICE integration is well-coordinated, and has the potential to proceed smoothly. The disconnect between the 201 MHz prototype cavity test schedule, coupling coil solenoids, and the production cavity schedule for the MICE, noted above under “201 MHz cavity”, is a cause for concern.

International Muon Ionization Cooling Experiment (MICE)

Alan Blondel, of the University of Geneva, gave a presentation of the plans for the International Muon Ionization Cooling Experiment (MICE). P. Drumm, from Rutherford Appleton Lab (RAL), also discussed the experiment from that laboratory’s perspective.

The experiment will use a cooling channel similar to that of design study 2, but with an additional set of windows around the absorbers (to meet safety requirements at RAL) and with smaller solenoids. The goals of the experiment are to show that it is possible to design, engineer, and build a section of cooling channel capable of giving the desired cooling performance for a neutrino factory.

Muon beam line at ISIS

The experiment will use a muon beam (with momentum about 200-400 MeV/c) from an internal target in ISIS, the spallation neutron source. The target will be re-worked for the MICE, and a new decay channel will be fabricated, leading to a large experimental hall in which the MICE will be staged. Some civil engineering will be required for the decay channel, which could use quadrupoles initially, but ultimately may utilize a solenoid from PSI to increase the muon flux by x10. Other particles will be rejected at the 10% level. RAL will supply the 8 MW of 201 MHz RF power required. Other infrastructure requirements in the experimental hall include 400 kW of ac power, 500 kW cryogenic cooling power, and the ability to facilitate liquid hydrogen handling.

Experimental Technique

Using single particle counting techniques, the MICE will measure transmission, and longitudinal and transverse emittance, of the muon beam, particle by particle. The goal is a clear measurement of ionization cooling (estimated to result in about a 10% reduction in transverse emittance).

The positions, angles, times, and energies of incoming and outgoing muons will be measured, using scintillating fiber trackers in solenoids located upstream and downstream from the cooling channel. The required resolution is better than 10% of the width of the beam. Particle identification will be required, to be sure that only muons are measured. This will be done using time-of-flight for the incoming muons, and Cerenkov radiation for the incoming and outgoing muons.

As noted above, the dark current in the RF cavities is a possible source of background in the scintillating fiber detectors. From the 805 MHz cavity measurements, the dark current induced background rate has been estimated at 500 kHz per fiber plane. Simulations indicate that background rates even 1000 times higher than this would be tolerable in the baseline detector, which has 43,000 channels and is quite expensive (about 4 M Euro). Options to reduce the cost include multiplexing channels, and the use a He-filled TPC with GEM readout. This has a much longer response time, so that several muons would be seen per live time, but tracks can still be found.

In the RAL beamline, the experiment can obtain an emittance ratio measurement with a statistical error of 10^{-3} in 1 hour, using a solenoid focused decay channel, or in 10 hours using a quadrupole channel.. However, there are many potential sources of systematic errors, which have been carefully examined by the experimenters. These errors can come from the cooling system (absorbers, the RF system, the solenoids, misalignments in the channel, etc.), as well as from systematic differences between the upstream and downstream detectors. By careful construction and measurement, with well-integrated accelerator and experimental data acquisition, as well as through the use of measurements with some experimental variables modified (e.g., other absorbers, other optics and/or beam momentum, solenoid operation in no-flip mode, higher RF gradients, etc.), it is hoped to control the systematic errors on the emittance raio to below 10^{-3}.

The committee was impressed with the careful planning and thought which has gone into the design of the experiment, in particular, the thorough elaboration of possible systematic errors. A measurement of beam emittance with this level of precision has never before been accomplished, and it is clear that the experimental team appreciates the challenge and is prepared to take the appropriate steps to meet it. The committee encourages RAL to implement the solenoidal muon channel, as the increased muon flux will allow many runs with different experimental variables, which may be necessary for the proper identification of systematic errors.

Logistics, cost and schedule

The experiment has 142 investigators, with an overall cost 25.2 M Euro, with 14 M Euro in the cooling channel. The US contribution is about 8.5 M Euro, mostly in cooling. These are hardware costs only; total manpower is 176 FTE-years, 67 FTE-years from the US. The schedule for the experiment has the demonstration of ionization cooling in 2007. The critical path items are the solenoids and rf cavities for the cooling channel.

The experiment will be reviewed by RAL this spring, and the decision on approval will come shortly after. Integration into the ISIS schedule presents some challenges also, as a long shutdown is required for the civil engineering work for the beamline, and the required resources compete with other projects. It is possible that the quadrupole decay channel could be installed during the next long shutdown of ISIS, in March 2004.

The committee remains convinced that this experiment, which is absolutely required to validate the concept of ionization cooling, and the R&D leading to it should be the highest priority of the muon collaboration. Planning and design for the experiment have advanced dramatically since the last MUTAC meeting, and the schedule has become more realistic with the one exception of the cavity production start. The strong support of RAL for the experiment is very encouraging. With a positive outcome in the upcoming review process, the process of securing funding for the experiment will get a much-needed boost. The critical path for preparing for the experiment runs through the MUCOOL prototype tests and production unit fabrication.

6) International

MUTAC heard an interesting talk by Koji Yoshimura on Japanese activities toward a neutrino factory and their participation in the international collaboration. The scheme proposed makes extensive use of FFAG's (four each with momentum gain of 3, for a total gain from 0.3 to 20 GeV/c). Cooling is not mandatory, but would give more flux if available. The FFAG designs and R&D make extensive use of proton FFAG's under commissioning (0.5MeV) and construction (150MeV) at KEK. The plan would be to incorporate the neutrino factory into the J-PARC 50-GeV PS facility expected to start commissioning in 07. A staged approach toward realization has the objective of permitting physics exploration as each stage muon energy is achieved.

R&D activities cover diverse areas. These include FFAG design, convection-cooled liquid hydrogen absorbers, tracker for MICE, high field ferrite or ceramic loaded RF, targetry including high field sc solenoid prototypes, beam tests, and mercury loop studies of a conduction target. Many of these activities are well integrated into the international collaboration. In particular a convection cooled absorber design will be tested at Fermilab in 03.

The FFAG design and construction work is particularly noteworthy. Real designs are being developed, understood, and built.

The committee notes with pleasure, both the rich program outlined and the strong commitment to the international R&D collaborative effort.

7) Schedule, Funding, and Priorities.

DOE direct funding to MUCOOL (DOE-MC) has shown a severe downward trend since FY00 when it was $4.7M to FY03 expected funds of $1.4M. These funds are the main source of component (material) funding within MUCOOL (exclusive of NSF funds) and consequently they limit progress on fabrication of cavity, absorber, solenoid, and target prototype components. An increase of ~$1M would be extremely helpful and would speed up by about a year the ability to do integrated cooling channel testing.

However it should be noted that overall funding from all sources (though difficult for the committee to estimate) was ~ $7-8M in FY02 and expected to be almost ~$6M in FY03. There appear to have been substantial uncommitted funds in 02 that can carry to 03. (A large fraction is in GPP funds for Muon Test Area.) Even so, the fact that MUCOOL has obtained funding from other sources should not be a reason for DOE reduction. A large university community, partially supported by these other funds, has been integrated into the MUCOOL accelerator R&D activities and strengthens the program.

As we see it, the schedule appears to be unrealistically fast, independent of the funding question. The preliminary schedule presented called for bid package release for the MICE production (not MUCOOL prototypes) of Q2-04 for absorbers, Q4-04 for cavity, and Q2-05 for coupling coils. We believe that a complete integrated systems test of cooling components is necessary before proceeding to production for MICE (should those funds become available). Of particular note are tests of the 200MHz cavity and absorber in their expected magnetic fields, to investigate cavity performance and to test results of a magnet quench on the associated systems. The cavity tests at 800 MHz have not yet provided proof of operation in a magnetic field. Though a breakthrough may happen at any time, success here would appear key to proceeding with much of the 200MHz development. Additionally, as presently constrained by funding projections, RF systems will not be available in the MTA before 05. (An additional 0.5M$ for rf systems in 04 would speed up test capability by one year.)

The MICE schedule calls for a) one absorber and associated magnets in spring 06, b) one 4 cell cavity, coil, and 2 absorbers in fall 06, c) two cavities/coils and 3 absorber units in 07.

We suggest a further look at the integrated schedule.

The mercury jet target work has shown considerable promise. This technology has broader potential application than just for neutrino factories. The R&D is now at a phase where it is necessary to build a target test experiment which incorporates high magnetic field and high incident beam power. The present plan is estimated to cost ~$1.9M over 3 years in order to fabricate the solenoid, the power supplies, and the cryogenics, and to install in a beam line at BNL. Though this work shows great promise, MC and MUCOG must balance its priority relative to the cooling. We note that in FY03, $350K out of $1.4M is budgeted for targetry, and recognize that this is an institutional as well as a technical funding priority issue. Additional funds in out years would make it possible for this development to move in parallel with the cooling work.

MUTAC Committee Members Jan 03

Marty Breidenbach	SLAC	
Gerry Dugan	Cornell Univ	
Helen Edwards, Chair	DESY/FNAL	
Mike Harrison	BNL	excused
Jerome Hastings	SLAC	
Young-Kee Kim	LBL	
Joe Lykkens	FNAL	absent
Al McInturff	LBL	
Ron Ruth	SLAC	excused
Koaru Yokoya	KEK	

marty breidenbach <mib@slac.stanford.edu>,
gerry dugan <dugan@lns62.lns.cornell.edu>,
helen edwards <hedwards@fnal.gov>,
michael harrison <harrison@bnl.gov>,
jerry hastings <jbh@slac.stanford.edu>,
young kee kim <ykkim@lbl.gov>,
joe lykken <lykken@fnal.gov>,
al mcinturff <mcinturff@seminole.lbl.gov>,
ron ruth <rruth@slac.stanford.edu>,
koaru yokoya <kaoru.yokoya@kek.jp>,

AGENDA MUTAC03

Tuesday, January 14

Time	Topic	Speaker	Duration
8:00 - 8:30	EXECUTIVE SESSION		30
8:30 - 9:10	Report of Spokesperson	Geer	30+10
9:10 - 9:45	Report of Project Manager	Zisman	30+5
9:45 - 10:10	Neutrino Factory Physics Program	de Gouvea	20+5
10:10 - 10:25	Break		
10:25 - 10:40	Theory and Simulation Introduction and Plans	Raja	10+5
10:40 - 11:00	Phase Rotation	Neuffer	15+5
11:00 - 11:25	Progress in Ring Cooler Designs	Palmer	20+5
11:25 - 11:45	Acceleration System Simulations	Berg	15+5
11:45 - 12:00	Pulsed Acceleration	Summers	10+5
12:00 - 1:00	Lunch		
1:00 - 1:35	NSF Muon Beam R&D Program Overview	Hartill	30+5
1:35 - 2:00	Superconducting RF R&D	Padamsee	20+5
2:00 - 2:35	MUCOOL Overview and Plans	Kaplan	30+5
2:35 - 3:10	NCRF R&D Program and Plans	Li	30+5
3:10 - 3:30	RF Background Studies and Plans	Torun	15+5
3:30 - 3:45	Break		
3:45 - 4:00	ICAR Program Overview and Plans	Morrison	10+5
4:00 - 4:30	LH2 Absorber Program and Plans	Cummings (?)	25+5
4:30 - 4:45	Cooling Channel Instrumentation	Errede	10+5
5:00	EXECUTIVE SESSION		
7:00	Dinner		

Wednesday, January 15, 2003

Time	Topic	Speaker	Duration
8:00 - 8:40	Targetry Overview and Plans	McDonald	30+10
8:40 - 8:55	Target Simulations	Samulyak	10+5
8:55 - 9:35	Targetry Magnet Design Status	Kirk	30+10
9:35 - 10:30	MICE Overview and Approach	Blondel	45+10
10:30 - 10:45	Break		
10:45 - 11:20	MICE Technical Update and RAL Plans	Drumm	30+5
11:20 - 11:50	Report from EMCOG	Blondel	20+10
11:50 - 12:10	Report from Japan	Yoshimura	15+5
12:10 - 12:30	Summary	Palmer	20
1:00 - 2:00	Lunch + EXECUTIVE SESSION		
3:00 - 4:00	CLOSEOUT		60
4:00	**ADJOURN**		