MUTAC Committee Report on the Muon Collaboration Review April 28-29, 2004

MUTAC Charge
April 28-29, 2004

1. Review and comment on the R&D progress achieved since the last MUTAC Review.

2. Review and give advice on the R&D plans and corresponding budgets for FY04, as well as on the long-range directions.

3. Assess and give advice on plans for the Targetry R&D program, particularly the enhanced focus on international activities.

4. Assess and comment on the relationship between Neutrino Factory R&D in the US and corresponding efforts in Europe and Japan.

5. Assess and comment on plans and progress toward a third-generation simulation and design study.

6. Review and comment on the status and scope of the US involvement in the MICE experiment.

Summary

The Muon Collaboration continues to make significant progress, but with very constrained M&S funding. As last year, 1M$ more would make a significant impact. This is especially true in light of the questionable ICAR funds, and the opportunity to do the CERN target experiment. We do wonder about the relative priority given the target and the cooling rf, however additional funds would make it possible to proceed more effectively on both fronts.

We did not review MICE, however US support on MICE is important for the international preparation to proceed. Approval of the US MICE proposal would have significant positive impact on the Muon Collaboration and its ability to develop hardware.

The Committee's area of greatest technical concern is the normal conducting 200 MHz rf systems operating in a background magnetic field. Here we recommend that a well defined R&D plan be developed which extends beyond the immediate tests. The superconducting rf R&D plan as proposed by Cornell is endorsed by the Committee. MUTAC compliments the Collaboration on the timely completion of the MuCool Test Area and the effective utilization of Fermilab resources in this regard. The MuCool ionization cooling R&D is proceeding effectively without any major unforeseen technical problems. The Committee considers the targetry work to be well focused on the important areas of a mercury jet beam test at CERN and jet simulation software.

At the current M&S funding level of $1.4M it is clear that hardware development is severely constrained. The Committee is concerned that it will be difficult to meet the desired schedule for the CERN target tests with this level of support. Understanding the CERN commitment to these beam tests will be crucial in this regard. MUTAC believes that the Collaboration may need to examine relative technical priorities of the target tests and the MTA proof-of-principle 200 MHz cooling rf tests when the CERN level of support is known. In a similar fashion to the previous meeting, MUTAC notes that the addition of $1M to the M&S budget would have a considerable positive impact on the R&D work and would allow parallel activities in targetry and the 200 MHz rf work.

The Committee commends the continued work in the conceptual design of a Neutrino Factory with the dual goal of cost reduction and performance enhancement. Notable in this area is the investigation of the use of FFAG's instead of recirculating linacs, ring coolers, and the use of gaseous hydrogen in ionization cooling.

In view of the limited manpower for simulation studies we would like to suggest putting priority on comparison of neutrino factory design with and without cooling. Japanese colleagues have a different scenario for a neutrino factory without cooling, putting more emphasis on the cost issue. The difference between the two scenarios with and without cooling is not only in the cooling part but also everywhere after the target. Since the two scenarios may give very different scope for the R&D program and the construction timeline, the comparison between them are quite urgent.

The Committee notes the significant progress achieved in establishing a worldwide collaboration and the integration of the various R&D programs. In particular Japanese participation has increased in many areas such as MuCool, MICE, targetry, FFAG and NuFact workshops. The MICE proposal is an example of the effective operation of this larger collaboration.

With respect to the MICE proposal, the Committee agrees that this experiment would represent a major step in establishing ionization cooling viability. The proposed US contribution in the cooling channel is a natural extension of the MuCool R&D program and is thus well matched to US expertise. While MUTAC did not review the cost estimate for MICE, we note that the ~$25M request to the NSF if successful, would represent a significant increase in the overall program. It is likely that the MuCool program would need to be revisited in this eventuality. The Committee perceived there to be schedule inconsistency or uncertainty between a technically achievable schedule, the NSF request, and the MICE proposal.

Finally MUTAC notes that significant studies of neutrino physics and programs are in progress in the community organized by the DPF. It is imperative that the Muon Collaboration take part and be well represented in this process. The relative importance of Neutrino Factory R&D must be established so that the technology is in hand on the time scale that it is needed.

Discussion and Full Response to the Charge

The physics

The status and prospects for neutrino experiments was presented (Harris). The measurement of θ_{13} , understanding of the mass hierarchy, and searching for CP violation (and measuring the absolute mass scale and determining if neutrinos are Majorana or Dirac particles) are critical and compelling problems in neutrino physics. It is also clear that a neutrino factory would be a powerful tool for the first three of these questions. It is less clear, since the situation depends on what the actual parameter values are, whether significant progress can be made with more conventional accelerator beams (and reactors). It is quite likely that no one will wait for a neutrino factory to arrive, that available beams will be pushed as far as they will go, and that there will be interest in proton drivers and β beams. Consequently, the urgency of the R&D for a neutrino factory relative to support for current and near term experiments is a difficult question, complicated by limited resources. Significant studies of neutrino physics and programs are in progress in the community organized by DPF. Participation in these studies by the Muon Collaboration is important in order to assure development of an integrated long term plan.

1. Review and comment on the R&D progress achieved since the last MUTAC Review.
(This section also includes comments on future R&D plans (2a).)

R&D to discuss:

- Targetry (see Question 3)
- SRF
- MuCool- MTA
- NRF, and background studies
- Cooling channel, Liquid H2 Absorbers
- Accelerator Systems,Theory, Simulation, Cost reduction (see Question 5)

SRF
200MHz superconducting rf is being developed for the muon acceleration. This rf would be used in linac section acceleration, FFAGs or RLA accelerators. Cost model estimates (Palmer) indicate normal conducting rf is of order 2.4 times as expensive as SRF. The high gradient and large aperture possible with SRF helps minimize muon decay loss during acceleration. SRF cannot be used in ionization cooling where strong magnetic focusing is required. Nb sputtered on Cu is used because of the excessive cost that would result from solid Nb cavities. It should be noted that 1.3GHz cavities made from Nb-Cu explosive bonding have achieved performance equivalent to solid Nb cavities and represent an alternative to sputtered Nb, though with additional use of Nb material.

Cornell University with funding from NSF is carrying out the SRF development. To date two single cell 200MHz cavities have been built and tested. Nb is deposited on Cu at CERN using the process developed for LEP and cavities are prepared there for vertical dewar testing at Cornell.

Test results of the 1st cavity achieved 11MV/m gradient at 7e8 and indicated a strong Q slope with gradient. Nominal design values are 15-17 MV/m and Q6e9. The measured Q slope is ~10 times larger than projected from the LEP 400 MHz cavities.
Studies of cavity #2 operation at low gradient with an external magnetic field (to simulate stray fields from an adjacent solenoid) indicate that if the cavity is superconducting before the external field is turned on, then external fields of 1200 Oe can be tolerated without Q degradation. This is consistent with HC1 of Nb. Further studies as function of gradient are planned.

The future program includes a recoating of one of the 200MHz cavities, and the pursuit of R&D on 500 MHz cavities that are much easier to handle and carry out exploratory tests on. The program plans to carry out investigations on Nb deposition techniques such as bias sputtering, vacuum deposition, and surface analysis in order to try to better understand the Q slope and determine most effective procedures. Studies of sputtered cavities have broad application.

The committee feels that concentration on the basic methods of deposition and the understanding of the Q slope phenomena, as Cornell proposes, is the direction this R&D should go rather than continued emphasis on 200 MHz testing. We note that 11MV/m not 17MV/m is being used in the present accelerator design work (Berg talk).

MuCool- MTA

The MuCool part of the Muon Collaboration is charged with: design, prototype and test of all cooling channel components, high beam power engineering test of cooling sections, and support in the MICE (low beam power) experiment. The MuCool collaboration includes participation from England and Japan.

The major R&D challenges for the cooling channel include: normal conducting RF operation in a strong solenoid field, sufficient heat transfer from the channel absorbers, acceptable amount of non absorber material in the channel aperture, and cost effective design.

A facility (MuCool Test Area- MTA) is being constructed at Fermilab in order to carry out the component test and use the Fermilab linac beam to measure heat extraction from the LH2 Absorbers. Civil construction of the MTA is complete and technical infrastructure installation has started. The test schedule calls for:

KEK absorber test I	May
RF waffle grid test	June
Curved Be window test	July

KEK absorber test II	Aug
RF button chamber data runs	Sept
201 MHz cavity test	Dec
Cryogenic install comp	Feb05

Fermilab is providing personnel for engineering design and infrastructure installation. A FNAL study group has been formed to design the 400MeV beamline from the linac to MTA. The time to realization of this beam transport is uncertain. Schedule calls for using beam in 06.

MTA Instrumentation

The committee heard a presentation from Debbie Errede of the University of Illinois on instrumentation for the Muon Test Area (MTA) at Fermilab. The instrumentation specifications appear to be comprehensive, including considerations of the necessary provisions for safe operation in the vicinity of a source of liquid hydrogen. The speaker mentioned the need for some of the instrumentation to be fully qualified for operation in a cryogenic environment; this qualification should be carried out as soon as possible.

NRF

The cooling channel design relies on 200 MHz Normal Conducting RF (NRF) cavities operation in a strong magnetic solenoid field. Present design for the 200MHz nrf utilizes solenoid fields ~3 T, and gradients of 16-17 MV/m. The achieved gradient with the 805MHz normal-conducting cavity under magnetic field is considerably lower than the desired value. It is not completely clear (at least to the committee) just how the scaling of the achieved operation at 805 MHz is expected to extrapolate for 200MHz. (If one assumes a Kilpatrick like scaling, it would imply 200MHz achievable gradient might be ~1/2 of 800 MHz gradient.)

Tests to date have been carried out at 805MHz in Lab G at Fermilab. These tests were terminated at the end of Dec because the TEVATRON operation needed the klystron. Best RF gradient results to date are with a cavity with TiN coated Be windows. The Be windows show no damage, however copper from other regions of the cavity has been sputtered on the window. At 8MV/m dark current is sufficiently low to be acceptable for the MICE experiment. "Safe" operating gradients of ~ 16MV/m have been achieved at solenoid fields of ~2.8T. However the copper sputtering problem remains.

Committee members feel it is unfortunate that an investigation has not taken place to try to determine just what areas of the cavity the Cu is coming from. There may be some corrective action possible if one knew the region of the source. We recommend that consideration be given to carrying out an inspection of the inside of the cavity while the RF is being set up and recommissioned at MTA.

Grid and button cavity studies

At 805MHz the grid concept of cell termination (instead of windows) is about to be tested. The effects of field enhancement of the grids will be explored.

A button cavity of design similar to the present 805 MHz pillbox cavity is under preparation. The button will produce a field enhancement relative to the rest of the cavity and the button material can be interchanged to determine just what materials or coatings appear to be best to increase breakdown level. Tests are not planned to begin till fall. Experiments using materials like those studied for CLIC other than copper and the proposed button cavity tests will be useful but it will also be beneficial to understand the underlying physics of the plot of gradient-vs-magnetic field including the scaling with frequency.

While these tests will be very interesting and may lead to greater understanding, we still recommend that consideration be given to inspection of the present cavity while the RF infrastructure is being set up at MTA.

The MuCool people should make sure they are completely aware of the studies carried out at CLIC (and others) on gradient behavior of different materials, and bring in expertise from other similar NRF studies.

NRF work still has substantial challenges. The committee recommends that focus be brought to this area thru a well defined R&D plan, defining not just button tests but also near term investigations and follow-up studies.

201 MHz cavity work

The 201 MHz cavity is designed for 17MV/m on axis field. The window design has been changed to use curved windows similar to the absorber windows. This appears to be a very good idea and considerably reduces the difficulty and cost of making the windows. Cavity production is going well. Testing of the 200 MHz cavity is planned for this late fall.

Based on funding constraints, there is no present plan to use a solenoid magnet of design specifications in the 200MHz tests; rather the present magnet (used with 800MHz) will be located at one end of the cavity. This short cut may be a mistake, as it is unclear just how well this will model final magnetic field configurations. As the source Cu sputtering on the window may come from interior of the cavity, that source point may not see appropriate magnetic fields. The collaboration should make sure they are confident that the planned tests using the 800 MHz solenoid will provide realistic and meaningful measurement.

Successful certification of 200MHz cavity design operation is just as important as the integrated target test under consideration at CERN. The risk and lack of information in meeting the requirements of a neutrino factory design is greater in the cooling rf area than in the target area at this time.

RF background studies and workshop on RF breakdown

MICE will be sensitive to detector backgrounds caused by dark current electron and secondary photons. Measurements of background counting rates were carried out at Lab G on the 805MHz cavity. The threshold of increased rate changed as tests were done: before solenoid field excitation, with solenoid field excitation to 2.5T, and at no excitation after the 2.5T excitation. As expected rates were worse with the solenoid on and did not return to the pre solenoid excitation level after the solenoid was turned off. The conclusion of the study was that rates appeared to be all right for the MICE experiment at the 8MV/m level, which should be acceptable.

The background rates must be measured on the 200MHz cavity to see if it will be adequate for MICE. Detailed simulations of the effect of background on MICE are underway.

Liquid Hydrogen Absorber R&D

At the review, the committee heard from Mary Anne Cummings on work being done at NIU and the University of Mississippi, partially under the sponsorship of ICAR and NICADD, on liquid hydrogen (LH2) absorber window R&D. Work on the LH2 absorbers themselves was reported by Shigeru Ishimoto, from KEK.

The absorber window is challenging, as the window must be as thin as possible and made from a low-Z material, to limit multiple Coulomb scattering. At the same time, it must be able to satisfy strict safety requirements established for containment of liquid hydrogen. Using FEA techniques, novel window designs have been developed at NIU, manufactured at the University of Mississippi, and tested at Fermilab. The tests have involved innovative photogrammetric measurements to determine the shape of the window under pressure, as well as standard pressure vessel burst tests. Designs and tests for absorber and safety windows suitable for the MICE experiment have also been performed.

Convection-cooled designs for LH2 absorbers have been developed at KEK. Prototype absorbers have been fabricated and tested in 2001 and 2002 at KEK. An absorber design suitable for the MICE experiment has been developed in 2003 and 2004, tested successfully at KEK, and is about to be tested in the MTA area at Fermilab. KEK will then fabricate the rest of the absorbers needed for the MICE experiment and ship to RAL. Design work is also underway for an absorber with forced-flow cooling, which would be suitable for high-power beam tests with protons at the MTA at Fermilab.

Steps in the Absorber Tests

The May 04 test is with a KEK convection type MuCool absorber of 21 cm diameter, thick windows and ~50watts deposited via heating. The August test is the same but with a MICE type KEK convection absorber with 30 cm diameter. The final MICE type KEK convention absorber is planned to be tested with thin windows at RAL in June 06.

The first MuCool forced flow type absorber test is scheduled for July 06 at MTA with beam in order to deposit ~350 W. The Neutrino Factory heat loads are expected to be ~few hundred watt. If ring coolers are used then this increased to ~10kW.

Conclusion- LH2 Absorber

LH2 absorber work looks like it is proceeding very well and that it is closing on the design. The committee applauds the excellent and innovative work done on the LH2 window and absorber development, and is pleased to see the significant involvement of university researchers in this development. It appears that the absorber R&D for MICE is essentially complete. In addition to developing designs for higher-performance absorbers, the committee encourages the design team to turn their well-developed tools and expertise to other areas, such as RF cavity window design.

Gaseous Hydrogen R&D

The committee heard a report from Rol Johnson on an STTR project to develop RF cavities operating in high pressure hydrogen or helium gas, suitable for use in muon cooling applications. A copper test cell, operating at 805 MHz, has been built and operated with high pressure (up to 400 psia) hydrogen gas at 77 K. Within the cell, peak RF fields of up to 70-80 MV/m have been demonstrated. Plans are being developed to test other electrode materials, such as molybdenum, and to operate the test cell in a 5 T solenoid at LBNL, at pressures up to 1600 psia.

Johnson also described several other muon-related SBIR/STTR projects in which his company, Muons, Inc., is engaged. These include studies of six-dimensional cooling in gas-filled linear channels with helical dipoles, cryogenic pulse compressors, a gaseous version of MICE called MANX, a hydrogen cryostat, and ionization cooling enhancements through the use of parametric resonances.

The committee encourages the development and test of novel approaches to ionization cooling techniques, such as the use of RF cavities operating in gaseous hydrogen, and the other exploratory ideas. Such innovations could lead to significant improvements in performance or reduction in cost, and are worth pursuing vigorously. Tests on gaseous hydrogen should be pursued vigorously with field and a more realistic cavity design.

2. Review and give advice on the R&D plans and corresponding budgets for FY04, as well as on the long-range directions.

The R&D plans for FY04 consist of:

- Participation in the MICE experiment.
- Implementation the MuCool test area (MTA) and continued fabrication and test of absorbers
- Continued fabrication of high field magnet for beam based targeting studies while evaluating the other equipment needed for a high powered beam test at CERN (Power supplies, Cryogenics, Jet System, etc)

- Continued development and testing of 800 and 200 MHz NRF structures in a solenoidal field. (We note the 200 MHz tests will not have a realistic magnetic field configuration).
- Continued testing of the SRF cavities, while pursuing investigations of different Nb on Cu surface preparations
- Continue to evaluate alternate designs at both the conceptual and component level.

MUTAC's comments regarding the MICE proposal are given in Section 6 of this report. We note that the substantial funding associated with MICE is contained in a stand-alone proposal to the NSF and hence is of a different nature from the baseline R&D funds, which are now defined for FY04. The NSF proposal, that was not reviewed by MUTAC, would essentially double today's funding if added to a flat budget. It would lead to significant development and test of the cooling channel engineering and physics. It is impossible for this committee to place it in any priority context relative to NSF overall funding and overall priorities. However the Committee does consider a detailed study of ionization cooling as represented by the MICE proposal to be a necessary step in the development of neutrino factories/muon colliders.

The biggest item in the FY04 R&D budget concerns the cooling work associated with the Fermilab MuCool Test Area (MTA). This R&D work includes absorber tests of different designs and eventually with high beam power, and RF development leading to 200MHz cavity operation in solenoid field. The Committee wishes to compliment the Collaboration for the efficient use of Fermilab resources to support the MTA and the work done to date. These engineering developments are for the most part needed for MICE, but the equipment built for MTA tests will not be sufficient for MICE. We also note that cooling channel systems engineered at Fermilab would precede independent of MICE but at a slower pace. The Committee feels that should the NSF approve the US MICE proposal then the scale of the US work associated with the cooling channel would both overlap and dwarf the proposed MuCool program. In view of this fact, the Committee suggests that when the result of the NSF request is known then the MuCool program needs to be reviewed in the context of the NSF's decision regarding MICE. The Committee believes that it is important to continue some form of development associated with an ionization cooling channel in all circumstances.

High power targetry R&D is the second biggest component of the FY04 budget. The Muon Collaboration wishes to carry out an integrated target test and has an apparent window of opportunity at CERN to do this important test in the first quarter of 2006. MUTAC believes that a high power beam test of a mercury jet in a magnetic field is a highly desirable technical step. It is clear though, that meeting this schedule will impose a great strain on the budget since significant funds will be needed in FY05. The Committee feels that the requirements to mount this experiment are still being established so there remains some uncertainty in the funding level and time extent that will be necessary. Of particular importance is the amount and availability of CERN hardware and manpower needed for a beam test. Any assumptions made regarding CERN resources need to be agreed upon in writing with the CERN management. The formal proposal submitted in April 04 is a good first step in this direction. MUTAC considers high power targetry to be an important issue for a wider constituency than just the Muon Collaboration (neutrino super-beams, radioactive beams, and spallation neutron sources, to name a few). In this context we urge the Collaboration to identify other possible interested parties from outside the Collaboration who could bring additional resources to the proposed beam tests. The Committee believes it will be difficult to meet the desired schedule with purely internal resources.

It is imperative to have a clear understanding of the CERN commitment and level of support for the target test. Some aid from CERN in this area could substantially reduce the funds required.

The ongoing effort involving the investigation of alternative design concepts such as ring coolers and hydrogen filled coolers, as well as continued work on cost reduction strategies provide an important mechanism for ensuring the intellectual vitality of the accelerator physics part of the Collaboration. The Committee finds the level of resources devoted to these activities to be appropriate.

A significant amount of support for the Collaboration is derived from sources other than the DOE; salary support from the HEP base program at FNAL and BNL, NSF support for the SRF R&D at Cornell, and the State of Illinois funds for ICAR. Total funding is approximately: 1.4M$ DOE M&S, 2.2M$ DOE Lab Salaries, 1M$ NSF, ~12 FTE ICAR.

It is unclear if funding from ICAR, which supplies personnel support to the cooling window design effort and other areas, will be continued. This will have a direct impact on the MuCool program. Additional funds from other sources could ameliorate this situation.

The HEP base program and NSF Cornell support are expected to stay essentially constant for the foreseeable future. In this context then, and in the absence of any approval for MICE, the Committee has a general level of concern that taking advantage of the available 'windows-of-opportunity' may be stressing the likely budget beyond a realistic point. The Committee believes that the collaboration must consider its priorities and reasonable development time scales and funding profiles rather than trying to push ahead too rapidly on all fronts with insufficient resources. NSF approval of the US MICE proposal would change this situation dramatically.

The funding for the neutrino factory R&D must be balanced with other shorter time scale neutrino experiments and beams. (See the Physics remarks in Other Comments section). Thus it is imperative that the Muon Collaboration take part and be well represented the APS DPF study of neutrinos and that possible time line of progression of neutrino beams and experiments be put forward. MUTAC notes the Snowmass meeting scheduled for the end of June as important in this regard.

At the present funding level of 1.4M$ DOE M&S, it is clear that hardware development is severely constrained. The collaboration believes it would need to fund items for the

CERN target test over 3 years. (Fy05-07) This appears inconsistent with the proposed schedule. The coupling coil for the 200 MHz cooling cavity test could not be built in the next years. In addition there is the question of ICAR personnel support.

The committee believes that the collaboration should seriously consider the relative technical priorities of the MTA coupling coil and the CERN target experiment, when it becomes more clear what the CERN support and time scale might be. A complete test of the cooling RF system is necessary as an existence proof of the cooling concept. On the other hand, the existing targetry measurements though not completely integrated, appear sufficient to establish targetry at reduced risk in achieving existence proof goals for a neutrino source relative to the risk associated with the cooling 200 MHz RF.

The addition of 1M$ to the M&S budget would have considerable positive impact on the development and program continuity of the hardware development and would allow for parallel activities in targetry and the 200 MHz coupling coil.

3. Assess and give advice on plans for the Targetry R&D program, particularly the enhanced focus on international activities.

The High power targetry R&D directed toward liquid metal targets capable of > 2MW beam power has focused over the last year on 3 areas of activity:

- Further development and plans for proof of principal experiment.
- Further development of simulations of the magneto-hydrodynamic process
- Participation in the international community through a workshop on targetry challenges over a broad range of application and in experiments with strong international collaboration.

Target Development

R&D over past years has been both in work on solid and liquid targets, with emphasis on liquid jet targets as they seem to be the most likely solution to high power beam targets (>2MW) with small beam spot sizes that are needed for efficient muon capture.

Work is continuing on solid target materials investigations into areas of material radiation damage, and irradiation effects on the coefficient of thermal expansion. These investigations are ongoing at little expense.

Studies of jet dispersal velocity and jet beam interaction have been carried out at BNL with positive results. Complimentary studies at CERN with the jet in a 20T solenoid field have also shown encouraging results. An integrated proof of principle experiment is proposed to test the operation of a jet with the design properties of Neutrino Factory (NF) Study 2., in a 15T solenoid with a beam of comparable power to that needed for the NF. The possibility exists to carry out this experiment at CERN PS in 2006. To prepare for this window of opportunity, development, construction and installation in a number of areas is required. The cost is non trivial compared with the overall Muon Collaboration and would most likely require additional funds to meet the installation goal of Q4-05 The component areas to be constructed include: the 15T solenoid magnet (under contract), power supply for the magnet (540k$), cryogenics (340k$), Hg Jet system (150k$), beam system (75k$), support (190k$). In total of ~1.4$ of future funds is required in order to mount and carry out this experiment.

This experiment is a very important final step in proof of principal of the jet concept, and one of the fundamental R&D areas of the muon program. Every effort should be made to see that the opportunity at CERN is not missed, as this beam appears extremely well suited to design study parameters. The protons equivalent to one neutrino factory bunch will be distributed over 500ns (instead of 7ns) but studies can be carried out to investigate the effect of time spread of the bunches and verify that the CERN beam is a good simulation in so far as jet dispersal is concerned.

Simulation effort

The very interesting and valuable target simulation work continues with further development of the code in two areas, and in application to other target designs (not just neutrino factory). In particular cavitation-modeling approaches have been implemented. The proper understanding of this process is key to obtaining simulations that agree with experiments. The two approaches are: direct numerical simulation of the evolution of bubbles in a fluid, and a Homogeneous Equation of State (EOS) Model where suitable average properties are determined to generate a pseudo fluid that can be treated with an equation of single component flow. The homogeneous simulation gives reasonable comparison of average shape and sound speed properties of the evolution of the jet but cannot address the more detailed evolution of filaments that emerge from the surface. The direct simulations are computationally expensive but give a better detailed picture. The direct numerical simulations are being used to investigate the SNS target cavitation problem and to analyze and optimize the idea of injection of gas bubbles to mitigate surface corrosion. This is a very important problem for spallation sources, but also comparison of the simulation with real ongoing measurements. Further simulation development will include coupling of the two simulation approaches together.

International activities

A Targetry Workshop was organized at Ronkonkoma, NY with participation from 13 laboratories including 5 foreign labs. The number of target applications and design parameters was very diverse from 21 different facilities including 12 under study. Conclusions from the workshop were that 1MW target exist but are unproven; no convincing solution exists yet for 4MW class machines. A concern was voiced at the lack of worldwide support facilities where new ideas can be tested.

Other activities with strong international involvement include the proposed CERN target test with representation from BNL, CERN, KEK, ORNL, Princeton, and RAL.

Further opportunities are developing under at EU FP6 program, with proposal for Neutrino Target R&D initiated by RAL in which the Muon Collaboration Target has adjunct status.

The evolution of the international interaction is very positive. It is through these international coalitions that R&D can best proceed with most efficient utilization of limited funds.

Conclusions- Targetry

The targetry work is very good and activities are well focused on the important areas of jet proof of principle demonstration and simulation development. The targetry group is integrating well into international participation and into interaction with targetry groups from a wide area of machine applications. Targetry development has broad application in many areas. MHD simulations are very nice, and well connected to experiments. Of specific note is the simulation work to understand the physics of the SNS target. It is important to carry through this program with the CERN experiment that seems timely and well planned.

The main difficulty is whether funds can reasonably be found and components built for the proposed CERN target test on the necessary schedule. We note that it would be a great help if either a power supply could be borrowed or an alternative cheap solution found. It is essential to understand as soon as possible if CERN will commit to this experiment with what resources and time schedule.

The CERN experiment should have high priority within collaboration, but must be balanced relative to the 200MHz proof of principle (See 2).

4. Assess and comment on the relationship between Neutrino Factory R&D in the US and corresponding efforts in Europe and Japan.

The Muon Collaboration is well integrated into the international R&D program for Neutrino factory and Muon collider R&D. It is participating with international colleagues in a number of different areas: targets, cooling and absorber development, overall design and simulation for muon factories.

- MuCool has a strong and active collaboration especially with Japan on absorber R$D and with UK.
- The proposed target experiment is a collaboration with Japan and CERN.
- The proposed MICE experiment has wide potential collaboration (UK, Japan, Italy, CERN) but must receive US funding to proceed in a timely fashion.
- Design studies and workshops on FFAG's (Fixed Field Alternating Gradient) are proceeding with collaboration from most importantly Japan, and with Canada and France. A non scaling FFAG electron model proposal is being developed with Japan.
- Participation is planed in separate Factory studies on "no cooling factories" with Japan, and on CERN based 2GeV Linac and Beta Beam with CERN.
- The annual International Nu-Fact Workshop and School continues.
- Last year the Target Workshop was held at BNL that discussed high power target R&D for beam power beyond 2MW.

It is very encouraging that US Neutrino Factory R&D seems well integrated into the world wide effort and that the international collaborations are growing.

The committee appreciates the remarkable progress of the worldwide collaboration. In particular Japanese participation was only minimal two years ago but by now they are collaborating in almost every field such as MUCOOL, MICE, targetry, FFAG and NuFact workshop. This is very much welcome as all large-scale machines should be constructed by world collaboration.

Organizational steps for the worldwide study a very good development. The comparison of US and Japanese FFAG and the utility of cooling study could perhaps be done as part of or a precursor to this study. The Japanese absorber R&D is exceptionally well integrated with the Mucool effort.

The worldwide study planning must address possible differences in US and CERN directions and accommodate the difference.

5. Assess and comment on plans and progress toward a third-generation simulation and design study.

Study 2a is being developed as a step toward determining the layout of the design to be undertaken in Study 3. Study 2a is derived from Study 2 with evolution in the direction of more cost effective designs and incorporating recent better design ideas. It is not in itself a full blown design but rather a searching of the parameter space.

The changes from study 2 are significant.
They include:

- Neuffer's bunched beam rotation scheme using multiple frequency NC RF instead of an induction linac. This allows for capture of both sign muons, potentially a factor of 2 gain.
- Shorter cooling section, based on optimization between acceleration section aperture and amount of cooling. Use of LiH for absorber instead of LH2 is being considered.
- Optimization of the acceleration scheme is being worked on and includes use of a linac to1.5GeV, a 1.5-5GeV dog bone RLA three arc sections, follower by two FFAG accelerators from 5-10 and 10-20 GeV acceleration.
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These ideas together make for considerable reduction beam line length, RF length and magnetic field length. The optimization the general design is based on crude cost models for different component types such as RF and magnets. This is not meant to be an engineering study but rather a tool for approximate parameter optimization.
This approach seems to be very useful as an optimization tool. However we suspect it is not a good tool to use to estimate overall savings relative to Study 2. That will need to wait till Study 3 is complete to the same level as Study 2.

The committee recognizes a great progress from study 2 to 2a. The acceleration using FFAG has been included in the design. The cost optimization process of RLA

(Recirculating Linear Accelerator) and FFAG has been established. The new design of acceleration by RLA followed by FFAG, together with the idea of bunching before phase rotation, which has been reported last year, leads to a significant cost reduction.

Several FFAGs are being operated and planned in Japan but all of them are scaled FFAG. Simulation works can study many subjects on the performance of a non-scaled FFAG. Nonetheless, it is desirable to have a low-energy prototype of non-scaled FFAG even though an electron machine as proposed.

Studies of various types of ring coolers, dipole ring, RFOFO and Li lens, have been reported. The designs are very much refined using realistic fields. The injection/extraction is also taken into account in the designs. We find significant progresses. A new concept of `phase ionization cooling' was introduced (Derbenev). A realistic design should be given and it should be clarified whether it helps not only for muon colliders but also for neutrino factory.

Simulation tools for cooling and acceleration have been improved including details of fields, and now they seem to be satisfactory.

In view of the limited manpower for simulation studies we would like to suggest putting priorities to various fields in the following order.
(1) Comparison of scenarios with and w/o cooling.
Japanese colleagues have a different scenario for a neutrino factory without cooling, putting more emphasis on the cost issue. The difference between the two scenarios with and without cooling is not only in the cooling part but also everywhere after the target. Since the two scenarios may give very different scope for the R&D program and the construction timeline, the comparison between them are quite urgent. The comparison study should include

* Refinement of Japanese design
* Storage ring design
* Physics comparison of figure-of-merit (like delta vs. theta13),
* Construction cost,
* Technologically possible timeline,
* A possibility of a machine starting without cooling with later addition of cooling.

It is highly desirable that the work is done with Japanese colleagues.
(2) Bunching, phase rotation, straight section cooling and acceleration. Continue further improvements of the design towards Study 3.
(3) Ring cooler.
Though the progress in this field is remarkable as stated above, this subject is less urgent than others. Longer term studies for muon colliders should continue.

<u>FFAGs</u>
Considerable work is going on world wide on FFAG designs. There twice per year international workshops that includes participation from Canada, Europe, Japan and US.
Japan is a leader in the design effort and is constructing 6 FFAG accelerators. PRISM a 20 MeV KE muon accelerator started construction in 2003.

Berg reported work on FFAG design for Study 2a. Lattice type and cost with energy range have been explored with the conclusion that a 2.5-5GeV FFAG is not cost effective relative to RLAs. Higher energy FFAGs (5-10 and 10-20 GeV) offer the possibility of substantial savings. Initial tracking studies with sextupoles of emittance growth and studies of longitudinal phase space distortions have begun. More work on detailed studies of FFAG dynamics will continue as will further design of the low energy acceleration section.

The sense of the committee is that considerable design effort is still necessary on FFAGs in order that their acceleration behavior becomes well understood and emittance growth estimated.

Electron demonstration model FFAG.

Discussions with in the US-Japan collaboration are taking place as to the value of an electron FFAG model. This model could address two dynamics phenomena of the non-scaling FFAG: rapid acceleration through integer resonances, and acceleration in "rf troughs" rather than buckets. The model would be at 10-20 MeV and 4.5 m in diameter.

Cooling Rings

The committee heard about various design options for cooling rings. The ideas are proceeding. Work on injection and extraction is planed. As ring coolers seem to have their most value for muon colliders they should be lower priority to the FFAG and low energy acceleration for Study 2a and Study 3. (See priorities above.)

6. Review and comment on the status and scope of the US involvement in the MICE experiment.

MICE

All concepts for a muon collider and most technical approaches to a neutrino factory rely on ionization cooling to reduce the muon beam emittance. Since this crucial technical process has not been experimentally demonstrated, the MICE (Muon Ionisation Cooling Experiment) proposal represents a major step on the road to establishing technical viability. Conceived as a highly precise single particle 'tracking' experiment it has a goal of verifying fractional emittance changes down to the 0.1% level. The MICE experiment is estimated to cost ~$75M in a US style cost estimate. Major contributions are anticipated from the UK, EU, and Japan, in addition the US. The proposal has been submitted to the Rutherford Lab in the UK and has received scientific approval and preliminary funding approval. Further progress is contingent on the MICE Collaboration securing international funding. The proposed US contribution is one third of the total and ~$25M has been requested from the NSF. Both the beam-line design and the experimental layout are well understood at this time and the short-term goal of the collaboration is to install the front-end of the MICE beam-line in the ISIS enclosure during an upcoming 'window-of-opportunity' in the ISIS running schedule.

The Committee notes with satisfaction the beneficial impact that MICE has had already. The international Collaboration of 150 members, formed to promote the experiment, is well organized and functioning. This is attested to by the significant progress achieved in the UK in obtaining the initial stages of the necessary approvals to proceed. Given the world-wide constraints on HEP resources, the international collaborative approach to the MICE experiment as well as significant US participation contained therein, is especially important.

The US involvement in the cooling channel for MICE is a natural extension of the MUCOOL R&D program and thus is well aligned and synergistic with the existing US program. The prospect of a beam test of the cooling channel components has resulted in detailed engineering with components from many different institutions integrated into a common design. This engineering in and of itself will provide a significant contribution to the postulated "world design study" in 2006. Indeed, MUTAC considers the engineering demonstration of realistic cooling channel components to be a highly significant activity in addition to the scientific goals of the program. With the availability of this engineering development the Committee would like to encourage the Collaboration to increase the realism in the experimental simulations to improve the understanding of the required data set.

The desire to take advantage of this available time window for work in the ISIS tunnel creates a need to receive funding authorization in the near future. Since the Committee received no details of the $25M funding estimate we have no comments on the reasonableness of the request to NSF. We did, however, perceive there to be a schedule disconnect between the NSF funding request, which was stated to involve a maximum rate of $5M/year and hence a 5+ year funding cycle, and the MICE schedule which had the complete experiment in place by 2008. It appears to MUTAC that even if the NSF funding request is successful, the experiment could not be staged on the schedule described by the Collaboration at this meeting.

Though much of the MICE-technical design seems quite solid, it is not clear from their presentations how all the crucial budgetary and resource issues play together and how getting the money later vs. earlier would impact the schedule. The schedule is not convincing in light of the absence of this information and more technical planning. The overall project plan needs to be articulated better.

The Committee does note however that the MICE concept lends itself well to a staged approach to the final experimental set-up. If the requested funding does not materialize on the desired time scale it could be possible to perform a less accurate series of initial measurements while still maintaining the option of the full experimental program at a future date.

MUTAC Committee Members April 04

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Gerry Dugan	Cornell Univ	
Helen Edwards, Chair	DESY/FNAL	
Mike Harrison	BNL	
Jerome Hastings	SLAC	Day 1
Young-Kee Kim	LBL	absent
Joe Lykkens	FNAL	absent
Al McInturff	LBL	excused
Ron Ruth	SLAC	excused
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