Hadronic Hose Review – October 2000

Physics Comments:

The Hadronic Hose (HH) will noticeably improve the MINOS physics results by decreasing both the statistical and systematic errors. The improvements, although not dramatic, enhance the capability of the experiment to investigate more complicated oscillation scenarios and to differentiate between oscillation and non-oscillation physics. The improvement in sensitivity will enable MINOS to more effectively determine the specific type of oscillations occurring and measure the oscillation parameters. Furthermore, the decreased errors will improve the quality of the oscillation fit, which will lead to a more convincing understanding of the oscillation phenomena and will allow more changes in the configuration with shorter runs.

The HH is especially important due to the ongoing K2K long baseline neutrino oscillation experiment in Japan. K2K will, presumably, have established a clear deficit in the ν_μ flux by the time that MINOS begins taking data in 2003. However, MINOS, due to its much higher event rate, will be capable of not only observing a deficit, but also of determining the cause of the deficit in a definitive manner. Therefore, this precision measurement capability is the hallmark of the MINOS experiment and provides a strong motivation for building the HH.

The HH has several important effects on neutrino flux:

- It increases the ν_μ flux by 25% for neutrino energies below 6 GeV at the far detector, when the low energy horn configuration is used. This low energy beam option is especially important at the energies where existing results on neutrino mass difference suggest $\nu_\mu \Rightarrow \nu_\tau$ oscillations should occur. The flux increase is even larger for neutrinos whose energies are greater than 6 GeV.
- It reduces the errors in the far/near flux ratio determination that are sensitive to hadronic production models.
- It reduces the flux errors that occur from misalignment of the focusing horns and other beamline components.
- It increases the ν_e background by a factor of two, but this is compensated by the previously mentioned increase in statistics, giving no change to the experimental sensitivity for the $\nu_\mu \Rightarrow \nu_e$ appearance measurement.
- It does not impact the need for better information on secondary particle production.

Comments about increasing flux:

In the case of the low energy MINOS beam, most relevant to the SuperK signal region, the statistical error will be decreased due to the 25% increase in neutrino flux in the critical region below 6 GeV. The HH increases the flux because pions that would hit the decay pipe wall are now channeled along the pipe and thus have a greater probability to decay. This focusing also affects higher energy pions, and for the low energy horn configuration increases the flux below 16 GeV by more than 50%. While the neutrinos above ~10 GeV may not be important in directly determining neutrino oscillation parameters, their interactions will serve as an important check on beam and detector systematics.

Since event rates in the near detector will be much higher than those in the far detector, a small amount of "HH off" data in the near detector could be useful in comparison to "HH on" data, in checking systematic effects.

The combined effects of the increase in the neutrino flux and the reduced systematic errors with the HH can be seen from studies done for $\nu_\mu \Rightarrow \nu_\tau$ oscillations with $\sin^2 2\theta = 1.0$ and $\Delta m^2 = 0.003$ eV^2. In this case a combined systematic and statistical error on Δm^2 of 0.0001 eV^2 is obtained after an exposure of 14.5 kiloton-yrs with the HH and the same error level is reached in 22.7 kiloton-yrs without the HH for the same number of 120 GeV protons on target. In addition, Monte Carlo studies where a large number of "MINOS experiments" was simulated concluded that a larger number of these "experiments" has false minima in the chi-squared distribution with the HH off than with the HH on, and that the fit resolutions are better with the HH on. In these studies spectral distortions corresponding to the production model uncertainty were included in the simulation.

Comments about flux ratio uncertainty from models:

The hadronic production models used to predict the secondary beam distributions for the calculation of the neutrino flux have significant uncertainties in the phase space relevant to the MINOS beam. The MINOS collaboration has calculated the expected ν_μ flux in their near and far detectors for four different production models (GFLUKA, BMPT, MARS and Malensek) which characterize three sets of production data: (1) Atherton et al. (CERN 80-07, 1980), (2) Barton et al. (Phys. Rev. 27, (1983) 2580) and (3) NA56/SPY (Eur. Phys. J. C10, (1999) 605). The calculations from the different models result in somewhat different flux yields with the agreement in most cases being about 25%. For disappearance measurements, the systematic error associated with these model differences will be decreased because the additional focusing of the HH makes the fluxes seen by the near and far detectors much more similar. In this type of measurement the spectrum observed in the near detector is used to predict the neutrino flux in the far detector. As the acceptance of the two detectors is not the same, the comparison depends on precise knowledge of the neutrino beam kinematics, which is coupled to understanding the production of secondary particles in the beam. The HH reduces the acceptance differences of the far and near detectors, thus reducing the dependence of the disappearance measurement on the production models. For the low energy beam option, the HH reduces the production model uncertainty in the far/near flux prediction by a factor of two.

Comments about alignment and other component errors:

An additional benefit of the HH is a lessening of the effect of transverse misalignment of the horns relative to the incident proton beam. MINOS studies show that misalignment effects on flux ratios in the far/near detectors are better tolerated with the HH. For example, with the HH a 1.0mm transverse horn misalignment produces less than a 2% fluctuation in the far/near flux ratio. Without the HH such a fluctuation is observed for a 0.8mm horn transverse offset. Studies also indicate that the expected 1.5 mm sag in the 72 10m long sections of the Al HH wire are hardly noticeable.

Comments about ν_e background:

The HH, because it also provides stronger focusing for muons in the decay pipe, produces additional ν_e flux from muon decays in the pipe. This intrinsic ν_e flux constitutes a background to the ν_e appearance measurements. Although this increase is not a desirable effect, if combined with the increase in statistics provided by the HH it does not seem to reduce the sensitivity of MINOS to ν_e appearance measurements. The increase in the ν_e/ν_μ event ratio in the far detector for $E_\nu < 6$ GeV is about a factor of two, i.e. from 0.8% to 1.5%. However, the signal/$\sqrt{}$(background) remains almost constant since the signal increases by about 25% with the HH. The same ratios for the near detector are about a factor of two larger due to the increased phase space available for decay neutrino flux to subtend the near detector.

Comments about a dedicated secondary particle production experiment:

There is the issue of whether MINOS should embark on a secondary particle production measurement experiment such as P-907 and how this affects the need for the HH or vice versa. The MINOS experiment and the reviewers agree that an experimental determination of particle yields at values of x_f and p_t relevant to the MINOS beam configurations would be of benefit in determining the neutrino flux. Such knowledge would allow a critical check on the observed event spectrum in the near detector. It was noted that K2K is having trouble making such a check in their experiment. The reviewers support both the HH and a P-907 type experiment; neither obviates the need for the other; both would provide independent information that may be crucial in understanding neutrino oscillations or other possible interpretations of the experiment's observations. Since the near detector is the primary monitor, an accurate prediction of neutrino interactions in it will require accurate and relevant production (P-907) data that do not now exist.

Electrical Comments:

The committee would like to commend the work that has gone on in the last several months. The physicists, engineers and technicians have worked through all of the obstacles that have surfaced. All questions from the previous review were addressed.

The committee saw a working full size 40-ft section of the hose and decay pipe. Second generation fixes to further optimize the design were also discussed.

A prototype pulser was demonstrated on the single length of hose. This is a good approach and has allowed very good electrical characterization of the line.

The preliminary design of the power supply looks solid and completion/installation should not impact the schedule. The cost estimate looks more than adequate for the system.

Recommendations:

1. The experiment should produce a good set of specifications for the current wave shape that includes both short-term limits on the pulse to pulse current as well as long-term limits. These specifications should be tied to physics requirements. Spare capacity should be built in at this time since getting spare capacity may be difficult to add in the future.
2. Continue working on the prototype pulser with the next generation including the final output transformer. This will give the designers a good measurement of the total inductance of each of the 72 loads.
3. A full-scale model (Spice Simulation) will be required to predict the operating parameters of the current pulse for the full system. This should be started as soon as all inputs are known.
4. Alternative solutions of the interconnecting transmission line from section to section should be investigated. Perhaps a multi-conductor cable will reduce costs and sensitivity to moisture.
5. Safety aspects of the monitoring system should be evaluated.

Mechanical Comments:

The committee is impressed with the effort expended since our last review. The testing and continued outfitting of the full-scale mockup of the HH represents significant progress in resolving wire support and electrical feedthrough design issues. These efforts should continue for optimization of mechanical details, observing effects of long term pulsing, and establishing detailed installation procedures.

The required design information necessary for the civil contractor to proceed with the decay pipe installation is complete. Existing manpower allocation appears adequate though the fractional involvement of individuals of the design team as it is now constituted, could become an issue if their focus is diverted to other pressing needs. However, having a dedicated installation team with experienced people should help relieve engineering oversight demand during the installation. The costs both for fabrication and installation are consistent with the complexity of the design. Any deviation should be minimal and well within contingencies provided.

There are no mechanical engineering reasons to prevent the committee from recommending inclusion of the HH in the NuMI project.

Management Comments:

The cost estimate for the HH, the decay pipe cooling and the power supplies has not changed significantly over the past six months even after folding in the experience gained in building the prototype cell. These costs were done carefully and appear solid. The cost of the civil work will remain uncertain until negotiations are completed with the contractor. The outcome of these negotiations is difficult to predict and depends on the number of additional weeks needed to accomplish the changes. The contract changes are likely to result in a cost that is more than the original estimates but are unlikely to cause the total cost to exceed $3.25M. The results will be known in the next few weeks. If the total cost of the HH project comes in at around $3M, the review committee feels that the improvement in physics capability of the detector makes the HH a very good investment.

Exercises building the prototype cell have helped confirm the schedule estimates for the work on the hose hardware. The civil construction will be stretched by about four weeks. The work on the HH and the extension of the civil construction do not appear to impact the overall NuMI schedule. The changes to the civil construction contract, however, need to be concluded immediately.

There was no organization presented at the review. The people working on the project are of high quality and the resources allocated are quite reasonable. The effort is fragmented, however, with a lot of people working part time including the management. This could well be a threat to the schedule and could eat up the available float. Although a $3M project is small by Fermilab standards it needs a project manager who devotes more than half time to the project to ensure success. The HH project also needs to be integrated into the NuMI management structure so that there are clear lines of responsibility and authority.

Project Summary:

The HH Project seems to be fairly well engineered. There are some questions concerning the pulsing and actual wire supports but no real problems. Technical assessment would indicate that it is unlikely for them to have any dramatic problems with the system. The main question is with respect to costs that will be required by Healy and impact on the schedule. This is not perfectly known yet but a conservative estimate is $3.25M and at most a 3-month delay. The delay may not be real since Healy's work will probably have a slower schedule; adding the HH project will give Healy an excuse for any delays. The project may have to pay extra to Healy even without the HH.

Nothing mechanical/electrical is pushing the system technically; this is not a state-of-the-art project. It should be straightforward to monitor the system and know what is working at any time. The project engineering, management and oversight looks manageable although it will need to be increased if the project is to succeed on schedule. The project needs to be integrated into the full NuMI resource loaded schedule.

The statistical impact of the HH is not significantly large by itself but it makes the far/near comparison much more solid. It may be important for establishing the credibility of the results since the predictions of the far spectra will not be as dependent on the primary production models. The combination of the hose and P907 particle production results cover complementary systematic uncertainties, so a hadron production experiment in the right x_f and p_t regions will be useful to MINOS in reducing systematic errors. The hose makes the far/near comparison more robust independent of production spectrum whereas P907 allows one to understand and check the observed event spectrum independently in the near and the far detectors. Also, if nature is more complicated than simple $\nu_\mu \Rightarrow \nu_\tau$ single oscillation, then having more handles on the systematics will help to sort things out. The increase in statistics will allow one to do more changes with shorter runs and the expected oscillation effects should show up with somewhat less beam.

Anything that reduces systematics in a tough experiment should be done especially since the cost is on the order of a 3% increase.

The HH project cannot go in later so the decision needs to be made now.

Recommendations:

The committee recommends that the Hadronic Hose project go ahead. The hose would increase the flux by 25% in the critical region below 6 GeV and reduce the systematic uncertainty in the far/near comparison. Even if production spectra measurements were available, the committee feels that the reduced systematic uncertainties with the hose justifies the 3% cost increase of NuMI. The technical risks are minimal but the project is costly and will likely impose a modest schedule delay.