# COUPP mini-Review Report

December 19, 2009

At the request of PPD management a mini-Review of COUPP R&D plans was held at Fermilab on Dec. 10, 2008. The Charge and Committee membership and the Agenda for the talks are attached below as Appendix I and II. The report of the review committee is written as responses to the elements of the charge and follows:

## Committee Report:

**Dark Matter Overview: (including COUPP's role)**

The COUPP collaboration presented a series of talks describing the current state of Dark Matter searches, limits from other collaborations, and the role that COUPP current plays and can play in the future. The Scientific case for Dark Matter searches is compelling and COUPP's bubble chamber approach is very promising. COUPP has demonstrated the ability to detect nuclear recoils from the formation of a single bubble, while MIPs are invisible to better than one part in $10^{10}$. The ability to choose fluids with different nuclear spins provides a powerful handle to distinguish between spin-dependent and spin-independent nucleon-WIMP interactions. In fact results from the COUPP-2 kg (1 liter) run have already excluded the low-mass region of the DAMA/NaI signal for the special case of a proton-WIMP interaction and has the world-leading results in this corner of parameter space. Operation of the COUPP-4 kg (2 liter), and COUUP-60 kg device in the NUMI hall could significantly extend these results.

One disadvantage of the bubble chamber approach is the lack of a nuclear recoil energy measurement above a threshold. COUPP has been able to study backgrounds by varying this threshold. Another possible disadvantage is background from alpha-decays that result from the decay of heavy metals either in the fluid or in the walls of the quartz containment vessel. An interesting fact is that nuclear recoils begin with a single bubble while events initiated by an alpha begin with many bubbles. COUPP has begun collaboration with members of the Picasso collaboration to study the possibility of using the acoustic signal of the bubble as it forms to distinguish alpha decays from nuclear recoils. Success here could significantly reduce backgrounds and enhance the discovery potential of a larger bubble chamber experiment that would otherwise be background limited by residual alpha emitters.

COUPP needs to gain several orders of magnitude in background rate reduction relative to demonstrated levels to exploit the science potential of COUUP-60 or a possible future 500 kg detector (COUUP-500). R&D in fluid purification and achieving low residual alpha decay rates and/or rejection of alphas via their acoustic signature is crucial.

Achieving low backgrounds in COUUP-60 in a deep under ground site could provide competitive science results for spin-independent and general nucleon-wimp spin-dependent interactions. A proposal for a 500 kg device could then be quite compelling. This technique hold the promise for both a sensitive and cost effective means to search for Dark Matter. The committee believes that the scientific case to continue COUPP R&D is strong.

**What R&D has been done and what has been achieved with the small detectors.**

COUPP has completed three R&D runs in the NUMI near-detector hall.

- Run 1: Staring in 2005 they tried to operate a 1 liter chamber, this first run failed due to contamination of the liquid inside the chamber.
- Run 2: Starting later in 2005, they operated the same 1 liter chamber. This run produced the results leading to physics publications of interesting Dark Matter limits.
- Run 3: Starting in 2007 a new run was started with many improvements, but some data quality issues arose during the run. The collaboration believes the data will also be publishable.

These R&D runs allowed them to:

- Discover the residual "CO2" problem in the CF3I bottle. They then established a procedure to eliminate this by transferring to a secondary container before initiating a fill of their vessel.
- Demonstrate the feasibility of operating a bubble chamber in the regime needed for dark matter search. This is mainly demonstrated by the reasonable live time (~85%) achieved during Run 2.
- Demonstrate the efficiency of a bubble chamber dark matter search for the detection of DM assuming spin dependent cross section.
- Identify three significant limitations of their apparatus:
    1) Radon diffusion through an o-ring
    2) Wall events: assumed be alpha events that result from radon attached the quartz jar walls. These events are easily identified, but since the alphas form bubbles requiring the recompression of the chamber, they contribute to dead time.
    3) Purity of CF3I: It was understood that the purity out of the bottle is not sufficient and that a purification system based on distillation will be required.

For Run 3, improvements were made to eliminate some problems seen in Run 2:

- The radon diffusion problem was eliminated by replacing the rubber o-ring with a Teflon-coated Inconel seal. The results obtained with the new gasket show an improvement of x10 in the radon induced bubble rate.
- Because wall events were assumed to be contamination in the quartz vessel, they went through very detailed procedures to insure the vessel remained free of

contamination and radon exposure after fabrication. This did not solve the problem. As a result, they are now convinced that natural quartz has radioactive isotopes that produce alphas responsible for the bubbles produced near the wall of the jar. They believe that this problem will be solved using a synthetic quartz jar and have had these jars fabricated.

- To increase the purity of CF3I they distilled it before the fill.

In Run 3 they also attempted a muon veto with scintillator from old experiments at Fermilab. This muon veto did not work very well because the scintillator available as not thick enough to allow a threshold efficient for muons but with a low noise rate. Although acoustic detectors were installed, they did not operate properly because of poor acoustic impedance match.

The sorts of problems encountered are to be expected as one develops a new technology. The committee believes the COUPP collaboration has done a good job of identifying problems and adjusting the R&D program to develop plausible solutions for the next R&D run.

**What is the R&D is yet to be done and why is important that it be supported?**

The committee did not hear of any problems that were potential show stoppers to pushing this technique to higher sensitivity. However in several areas R&D must be completed if the collaboration is to proceed to larger and more sensitive devices. Important areas of R&D that deserve support include:

1) Demonstration of a reduced wall-rate with synthetic quartz vessels: The 2009 operation of COUPP-4 should provide information on this issue, as should the operation of COUUP-60.

2) Discrimination between nuclear recoils and alpha decays from the acoustic signal: COUPP-4 and COUUP-60 will be equipped with acoustic sensors to explore this possibility. In addition, a 1 liter test chamber will be completed and provided to collaborators from the Picasso experiment to enable a test-bed to optimize acoustic detection of alphas. The achievement of event-by-event discrimination could enable a factor of 100 background reduction, and could also be decisive in turning COUPP into a discovery experiment by confirming that a set of events is from nuclear recoils and not from a poorly understood alpha background.

3) Improved fluid handling and $CF_3I$ purity to reduce alpha-decays in the bulk: We heard a description of the new fluid handling system but no explicit plans were presented for how one could insure success. However, results achieved for neutrino experiments are promising.

**What are the prospects for this technology in larger detectors in the future? Include engineering issues, DAQ, siting, and required resources for COUPP 500.**

As mentioned above, the committee did not hear of any problems that would prevent pushing this technique to larger volumes and a deep underground site leading to higher sensitivity. The engineering issues of a larger detector are largely those associated with locating the device deep underground. In particular, the physical size of components that must fit down elevator shafts, the weight of components, and safety issues associated with working, welding, assembly, and fluid handling in a confined underground space must be addressed. It was pointed out that CF3I is a well understood liquid used for fire control. This will be very helpful in gaining safety approval to operate.

The principle challenge for larger detectors will be understand and control of backgrounds at a very low level. Success with COUUP-60 is a necessary condition to demonstrate that they're ready to take the step to a 500 kg device. The main issue in this step will be a reduction in the background rate / kg-day. It is possible that solutions to this problem could have significant impact on the engineering of the larger device.

The DAQ requirements seem quite modest and the issues to be addressed are largely those related to reliable operation in the remote and deep underground location. The committee did not think these issues were a significant problem.

Siting for a 500 kg detector is an important issue that needs to be understood early in the design phase since access sizes, weight limit, etc will vary depending on the site. Both Soudan and SNOLAB are candidate sites for COUUP-60 and later for COUUP-500. Soudan has the advantage that it is in the U.S. and there is an existing FNAL workforce with experience working there. However, there is not a local support laboratory. As a result needed technical resources must come from FNAL technical staff. SNOLAB is a better site from a scientific standpoint (i.e. it is deeper and therefore quieter) and the committee was informed that technical support and clean room space may be available from the existing lab. However, the difficulty of operating the detector in another country including approval processes, travel, etc needs to be understood. Pursuit of the siting issues for COUUP-60 and eventually COUUP-500 should have higher priority than the engineering design of the 500 kg detector at this time.

**At what point would R&D transition to detector specific or project work?**

The 500 kg device is likely to be sufficiently expensive that it should be treated as a project, at least within the Fermilab system. This would represent a natural time to transition to project work. The committee suggests the collaboration prepare a report on the COUUP-60 experience including analysis of backgrounds, a background and siting discussion for the 500 kg detector, a conceptual design of the 500 kg device, and an estimate of the cost and resources required. The laboratory management will determine

the next steps but a Director's Review followed by a review by the PAC seems a likely path.

**What is the level of financial and personnel resources needed for the next year and in the longer term?**

The collaboration presented a plan and schedule that required continuation of the existing Fermilab workforce of about 5 FTE. They argued for dedicated time from a few key engineers and techs. In addition they believe the entire program could be accomplished with about $ 300 K of M&S each year for the next 5 years.

The current COUPP engineering team is strong and certainly capable of executing this project. It is difficult to determine if the level of resources requested by the collaboration is sufficient without a realistic schedule and scope of work for all the various activities proposed. The committee encourages the PPD management to consider the importance of experience and continuity in this type of work as they make future personnel assignments.

Specific engineering issues include

1) For the deep underground locations in SNOLAB or SOUDAN is there still a need for the outer "water jacket" as a veto? If so what reliability is required for the enclosures/seals that protect cameras and electronics?
2) Is the ancillary equipment (cameras, acoustic sensors, instrumentation, etc.) sufficiently reliable for this application? What are the total hours of operation expected for this equipment? What "mean time between failure" is acceptable?
3) Are there operational procedures written for the various steps of fluid handling so that consistency is achieved?
4) Are there ways to gain confidence about the fluid handling system integrity before first operation? How about the use of a RGA to test piping for cleanliness in addition to with He leak check)?
5) Is the fluid handling system scalable to 500 kg or larger detectors? Will procedures/equipment need to be changed?
6) Can quartz jars and seals larger than those built for COUUP-60 be fabricated? What R&D is needed for this or alternatives and was that included in the estimated M&S?

The principle concern of the committee was that the schedule appeared to be unrealistic in that the 500 kg device design was occurring before results from the COUUP-60 were available. The collaboration has an ambitious plan to operate COUPP-4, a 1 liter acoustic sensor test bed, and COUUP-60 all at the same time including making plans to move COUUP-60 to a deep underground location. It seems hard to believe that the existing team can also simultaneously design a 500 kg device and pass the necessary reviews on the schedule indicated.

**Other Issues and Comments:**

If the problems with the 2 liter chamber seen in Run 3 are found to be corrected, and the muon veto is efficient, COUPP-4 seems likely to be able to publish interesting new results before COUUP-60 is fully operational.

Given limited resources, trying to commission COUUP-60, operate COUUP-4, commission/operate the acoustic sensor test bed device, and design the 500 kg device may be unrealistic. These detectors are unlikely to start up and operate without any issues. The collaboration should evaluate the priority of these various tasks and insure that schedules are realistic and their limited resources are used effectively. In particular, the engineering design of the 500 kg detector should probably await first results from COUUP-60.

The FNAL budget office maintains a list the M&S needs at the lab for the next 5 yrs. The COUPP effort is currently listed as needing $ 100 K M&S each year vs. the $ 300 K per year shown in presentations to the committee. There seems to be a communication problem among the collaboration, PPD management, Directorate, and/or Budget Office.

This review did not address detailed safety analysis, engineering details, or Operational Readiness. The committee assumes that appropriate reviews will be conducted by PPD.

The committee would like to commend for their success thus far and thank the COUPP collaboration for a very interesting and informative series of presentations to the committee.

# Appendix I: Charge

COUPP R&D Review Charge
Dec 10, 2008

R&D for HEP experiments in the US will have high priority for the next 5-10 years as we work to define the next generations of experiments that will push the boundaries of our knowledge in the energy, intensity, and cosmic frontiers. To that end, Fermilab needs to have a well focused program of detector R&D so that the directions taken are appropriate, understood, and supported. PPD is planning a series of mini-workshops to review the status, progress, and prospects for all known R&D efforts in the division. For your R&D, we would like to have a series of talks covering:

- Dark Matter Overview: ( including COUPP's role)
- What R&D has been done and what has been achieved with the small detectors.
- What is the R&D is yet to be done and why is important that it be supported?
- What are the prospects for this technology in larger detectors in the future? Include engineering issues, DAQ, siting, and required resources for COUPP 500.
- At what point would R&D transition to detector specific or project work?
- What is the level of financial and personnel resources needed for the next year and in the longer term?

The plan is to have a half-day mini-review whose outcome is a short report to the Division head covering the above questions. Please suggest an agenda with 2-3 hours of talks, including breaks, which address the above questions.

Bob Kephart will chair the review. Other reviewers are: Rich Stanek, Fritz DeJongh, Juan Estrada. The review will be open to interested scientists at the lab and user community as well. Your research efforts are vital to the labs future, and we look forward to a very interesting and productive review.

# Appendix II: Agenda

COUPP R&D Review. Dec. 10, 2008

12:30-5:00 pm, Hornet's Nest, Wilson Hall

12:30 Introduction to dark matter detection (Sonnenschein)
12:50 Overview of COUPP (Collar)
1:20 Operations and results from 2 kg chamber; plans for 4 kg upgrade (Crisler)
1:50 Break
2:00 COUPP-60 design and construction (Rucinski)
2:30 NuMI and deep underground site installations (Ramberg)
2:50 Video, trigger and DAQ for COUPP-60 (Cooper)
3:10 Background discrimination using acoustic sensors (Levine, by video hookup)
3:30 Schedule and resources (Sonnenschein)
4:00 Committee executive session
5:00 end