Filling, Commissioning and Deployment of the Antineutrino Detectors

Kirk T. McDonald
Joseph Henry Laboratories, Princeton University, Princeton, NJ 08544
(October 14, 2006; updated Oct. 15)

Abstract

Considerations of the filling, commissioning and deployment of the antineutrino detectors for the Daya Bay Experiment lead to (at least) 4 questions:

- Should the detectors be placed in water pools or surrounded by self-contained water modules?
- Should the commissioning include a Commissioning Hall in which 2 or more detectors can be operated with sufficient shielding to detect reactor antineutrinos?
- Should the detectors be transported filled or empty?
- Should the detector tanks be of steel or of low radioactivity "fiberglass"?

It may be that low cost, rapid deployment, and ease of movement of the detectors are best met by a simplified variant of the "aquarium" based on large PVC water tubes, together with fiberglass detectors that are moved empty. This scenario might permit early physics operation with a Mid Filling/Commissioning Hall, without compromise to the schedule for deployment of detectors in the Far and Ling Ao Halls.

1 Introduction

The primary goal of filling, commissioning and deployment of the antineutrino detectors should be to bring all 8 of these detectors online as quickly as possible after beneficial occupancy of the 3 detectors halls, the Daya Bay Near Hall (2 detectors), the Ling Ao Near Hall (2 detectors), and the Far Hall (4 detectors).

An important premise of this discussion is that the tunnel construction schedule should permit occupancy of the Daya Bay Near Hall about 12 months earlier than the other two halls.

Rapid deployment (and minimum cost) of the detector systems implies minimum time for construction of the detector halls, as well as minimum time of installation of the muon system and detectors in those halls. It also implies maximal opportunity to commission the detectors prior to their final installation.

1. Should the detectors be placed in water pools or surrounded by self-contained water modules?

The water-pool scenario, which is the baseline presented in the CDR [1], provides excellent shielding of the detector at the price of a large detector hall and the need for cranes in excess of 100-ton capacity.

While I have never been a fan of the "aquarium" scenario, I consider here a much simplified version of it, which could be called the "water-tube" option. This would permit smaller detector halls, with NO overhead cranes. The detectors would remain on their transporters at all times. One pair of detectors could be swapped without interruption of data taking of the 3 pairs.

2. Should the commissioning include a Commissioning Hall in which 2 or more detectors can be operated with sufficient shielding to detect reactor antineutrinos?

   The desire to reach modest sensitivity to $\sin^2 2\theta_{13}$ at an early date leads us to consider options in which 4 or more detectors can take initial data at two locations, the Daya Bay Near Hall, and the Mid Hall.

   Construction and outfitting of two halls based on the water-pool solution in parallel with tunneling to the Ling Ao and Far Halls may require too much time to make this option viable. Hence, an additional merit of the water-tube option could be to speed up the availability of the Daya Bay and Mid Halls for physics use.

3. Should the detectors be transported filled or empty?

   In the water-pool scenario, the transport of filled detectors requires cranes in excess of 100-tons to move the detectors into and out of the detector halls. The transport and lifting of heavy objects is inherently riskier (and more costly) than that for lighter objects. These risks could be mitigated (and the costs lowered, and the schedule advanced) by transport of empty detectors.

   Of course, if the detectors are transported empty, there must be storage facilities for the 3 types of liquids associated with each detector (≈ 40 tons of mineral oil, ≈ 20 tons of unloaded liquid scintillator, and ≈ 20 tons of Gd-loaded liquid scintillator). And there must be appropriate piping between the detector sites and the storage tanks. A detector-fluid distribution system would parallel that needed for distribution of water for the muon system.

   The baseline scenario calls for underground storage tanks with capacity for 2 detector's of each of the 3 types of liquids.

   The optional scenario for transport of empty detectors could be accomplished with the same 3 underground storage tanks, plus ≈ 10 km of PVC piping between the storage tanks in the Filling/Commissioning Hall and the 3 detector halls. For example, pipes with $1/2''$ ID and a flow rate of 1 m/s could accomplish the filling/emptying of a detector in 12 hours.[1]

4. Should the detector tanks be of steel or of low radioactivity "fiberglass"?

   If the outer tanks of the detector are made of 2-cm-thick steel, they will weigh about 18 tons each, while the inner acrylic cylinders bring the empty weight of each detector

[1] $1/2''$ Schedule 40 PVC pipe appears to cost about 1.5/m, so 10 km of such pipe would cost only $15k.

to about 21 tons. Even if the detectors are transported empty, the transporters and cranes must have substantial capacity.

If the outer tanks of the detectors were made of low-radioactivity "fiberglass", as were the 30-ton tanks used in GALLEX [2] (see Fig. 1), their weight would be about 3 tons each, and the empty weight of a detector about 7 tons. The transporters would need to be rated only for this capacity, although in the water-tubes scenario, the transporters would need to have auxiliary bracing to support the ≈ 87 ton weight of a filled detector when in place in a detector hall.

Figure 1: One of the two 30-ton low-radioactivity fiberglass tanks used in the GALLEX experiment [2].

2 The Water-Tube Option

The water-tube option is a variant of the "aquarium" that is considerably simpler, while retaining the merits of operation of dry detectors without the need for overhead cranes.

Figure 2 shows a minimal configuration for a water-tube shield for 4 antineutrino detectors. The 4 detectors are operated on their ≈ 0.5-m-high transporters, which are at grade level (with jacks to support the weight of the filled detectors).

Below and above the detectors are a pair of water pools 2.5-3 m thick. The lower pool must include a set of load-bearing columns that support the grade-level deck on which rests the 4 detectors and the array of vertical water tubes. The upper water pool could be hung

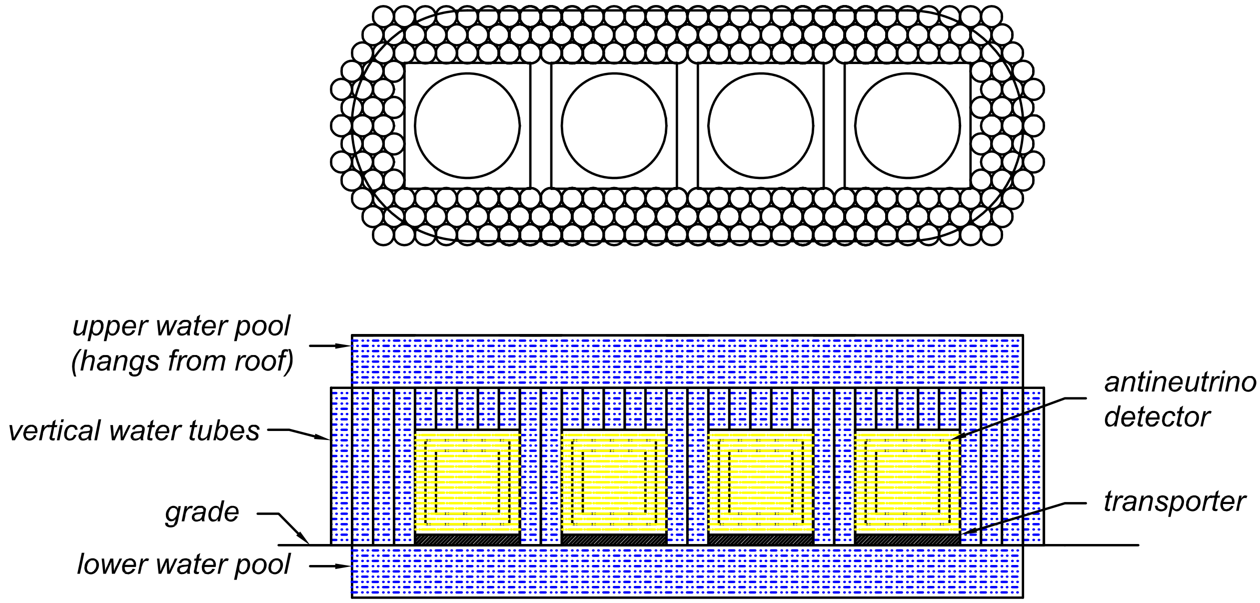

Figure 2: Possible configuration of water tubes and water pools surrounding 4 antineutrino detectors. The lower figure is a view in which the water tubes in front of the dectectors have been removed.

from the ceiling of the hall,[2] with possible additional support by steel columns interspersed among the water tubes.

The bottom of the upper water pool is 7.5 m above grade level, allowing a 2-m-high space above the antineutrino detectors for personnel access and calibration equipment. The minimal scenario shown in Fig. 2 does not include RPCs as they do not appear to this author to be necessary [3]. However, RPCs could readily be arrayed above and/or below the upper water pool, if desired.

The vertical water tubes are 1-m-diameter PVC tubes, as now available in the water handling industry.[3] They would be ≈ 7.5 m long, and would be equipped with one PMT at each end, as sketched in Fig. 3. It might be favorable to use $10''$ or $12''$ PMTs [4], rather than $8''$. The inner walls of the tube would be lined with a reflector such as Tyvek, or anodized aluminum sheets [5]. Another option (suggested by M. Diwan) is to line the water tubes with one or two "bags" of thin, transparent Mylar, leaving a thin layer of air between the Mylar and the tube that creates a total-internal reflection interface.

The array of water tubes should provide a minimum path of 2.5 m of water between the antineutrino detectors and the cavern walls, to suppress background radioactivity. The configuration shown in Fig. 2 provides a 2-m-long water path in all directions, and a path greater than 2.5 m in almost all directions. A simulation of the suppression of rock radioactivity by the water tubes should, of course, be performed to confirm that the design meets our requirements. A variant of the water-tube option is to add another layer of tubes, but only instrument the outer layers to the extent needed to achieve a specified muon-detection efficiency.

[2]Caverns in granitic rock can support ceiling loads of up to 5 tons/m^2, according to C. Laughton.

[3]Thanks to M. Diwan for bringing this to the author's attention.

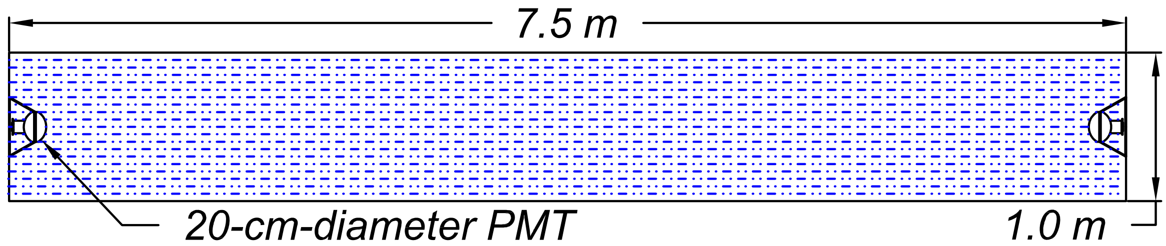

Figure 3: Sketch of a watertube, which is a 1-m-diameter PVC water pipe instrumented with 2 PMTs.

The water path length could be improved by use of (uninstrumented) 15-cm-diameter, water-filled PVC tubes that are placed in the interstices of the close packed array of 1-m-diameter water tubes.[4]

Access to a detector for swapping would be made by removal of a section of the water-tube array (after draining the water from this section only), as shown in Fig. 4 for a Near Hall.

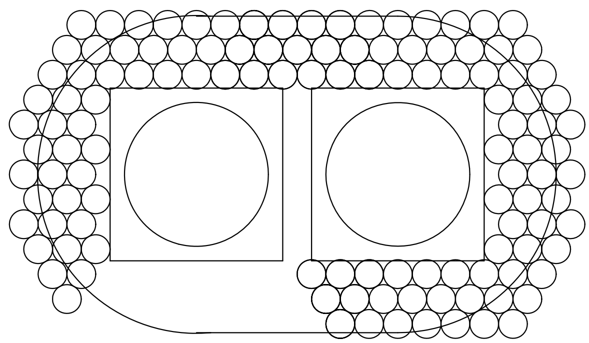

Figure 4: A Near-Hall water-tube array with some tubes removed so that one of the antineutrino detectors can be swapped to another hall.

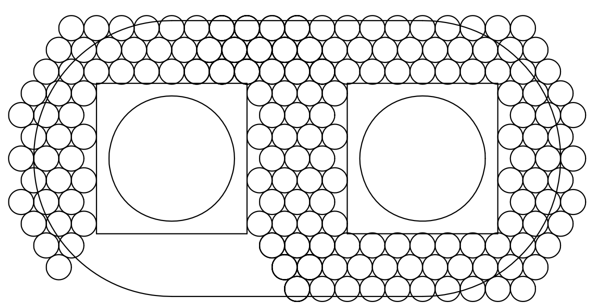

Figure 5: A Near-Hall water-tube array with tubes between the two antineutrino detectors, such that one detector could continue data collection while the other is being swapped.

It may be preferable to be able to swap a detector without interruption of data collection with the other detector(s) in the same hall. This could be accomplished with a slightly

[4]For close packing of cylinders of radius r, cylinders of radius $2\sqrt{3}/3 - 1)r = 0.155r$ can be placed in the interstices.

more extensive water-tube array, as shown in Fig. 5, with 3-4 layers of water tubes between neighboring detectors.

The water tubes could also be configured with chicanes so that there would be personnel access to the detectors at all times, while maintaining the 2-5-m water shield against rock radioactivity, as sketched in Fig. 6.

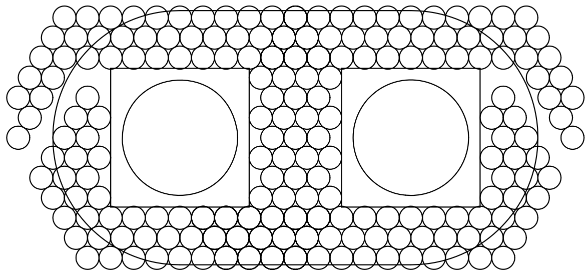

Figure 6: A Near-Hall water-tube array with chicanes for personnel access to the detectors.

References

[1] X. Guo *et al.*, *Daya Bay Project Physics Proposal* (Oct. 3, 2006),
http://dayabay.bnl.gov/private/documents/cdr/tex/cdr_review.pdf

[2] See sec. 2.2 of P. Anselmann *et al.*, *Solar neutrinos observed by GALLEX at Gran Sasso*, Phys. Lett. **B285**, 376 (1992),
http://kirkmcd.princeton.edu/examples/neutrinos/anselmann_pl_b285376_92.pdf

[3] K.T. McDonald, *On the Efficiency Requirement for the Muon System* (Oct. 5, 2006),
http://kirkmcd.princeton.edu/dayabay/efficiency.pdf

[4] For a summary of candidate PMTs, see,
http://kirkmcd.princeton.edu/dayabay/RPI_PMT.xls

[5] Very good UV reflectivity for large-area anodized aluminum sheets has been achieved by Anomet Inc. (www.anomet.com). See,
http://kirkmcd.princeton.edu/dayabay/Anomet/spectral_curve_MIRO_products.pdf