The Daya Bay Antineutrino Detectors

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US Antineutrino Detector System Manager

BNL
CD-3b Review
June 10, 2008
Outline

1. Scope of Task

2. Management and Review Status

3. Technical Status and Procurement of AD Subsystems
   - Design Status of CD-3B Items
   - Procurement Status of CD-3A Items

4. Response to CD-2/3a Recommendations

5. Status of US Cost, Schedule, Other Issues

6. Summary
Antineutrino Detector Task - Overview & Scope

- design & fabrication of all detector elements and instrumentation
- filling & target mass measurement
- scintillator preparation
- assembly

Karsten Heeger, Univ. Wisconsin  Daya Bay CD-3b Review, June 10, 2008
A Short Guide to the AD

- PMT cable feedthroughs and dry boxes
- calibration boxes
- reflectors
- gas and electrical distribution boxes
- overflow tanks
- calibration pipes
- auxiliary ports for monitoring and filling
- PMTs
- PMT ladders and mounts
- inner 3-m acrylic vessel
- acrylic support ribs
- outer 4-m acrylic vessel
- stainless steel vessel
Antineutrino Detector - Scope & Responsibilities

A Broad Overview (details in MOU list of deliverables)

Taiwan - blue
- 3m acrylic vessel with bonded lid

US - orange
- 4m acrylic vessel with removable lid
- acrylic overflow tanks for Gd-LS and LS
- cover gas system
- calibration pipes + bellows
- overflow tank instrumentation
- PMT mounts and ladders
- PMTs, bases, and testing
- PMT cables and feedthroughs
- Gd-LS and LS

PRC - grey
- stainless steel vessel (SSV)
- SSV lid
- reflector
- mineral oil (MO) overflow tank
- overflow tank instrumentation
- Gd-LS, LS, and MO
Antineutrino Detector Design Status & Reviews

Design Reviews Since CD-2/3a Review in Jan 2008

• Feb 2008
  – AV PRR
  – GdCl₃, THMA FDR
  – SSV PRR (PRC scope)
• Mar 2008
  – AD stand FDR (PRC scope)
• Apr 2008
  – LS production FDR
  – PMT mounts FDR
  – PMT cable feedthroughs FDR
  – AD PMT base FDR
  – AD PMT testing FDR
  – PMT cable routing PDR
  – lifting PDR (PRC scope)
  – AD temporary stand PDR (PRC scope)
• May 2008
  – ISO tank PRR

PDR = prelim design review
FDR = final design review
PRR= production readiness review

completed Final or Production Readiness Reviews in green
Preliminary Design Reviews in orange
reviews of PRC scope in grey
Antineutrino Detector Design Status & Reviews

Upcoming Design Reviews

- July 2008
  - AD instrumentation and monitoring FDR
  - AD lifting and temporary stand FDR (PRC scope)
  - reflectors FDR (PRC scope)
  - LS storage tanks FDR (PRC scope)
  - LS mixing FDR (joint scope)

- Aug 2008
  - AD filling and cover gas system FDR
  - AD assembly & installation PDR

- Oct 2008
  - AD assembly & installation FDR

→ instrumentation tested and characterized in the lab, long-term tests ongoing

→ components of filling system tested, no show stopper, final design and integration work

- design of AD well along. many individual components and instrumentation have been tested

- we are starting to plan AD assembly and installation
Antineutrino Detector Co-Managers

Jun Cao, IHEP - China
Karsten Heeger, UW - USA

L3 Management

1.1 Detector Tank *(Zhuang, IHEP)*

1.2 Acrylic Vessels *(Heeger, UW / Hsiung, NTU)*

1.3 Liquid Scintillator *(Yeh, BNL / Zhang, IHEP)*

1.4 PMT AD Mechanical Systems *(Virostek, LBNL / Cherwinka, UW)*

1.5 System for Measuring Physical Detector Properties *(Wise, UW)*

1.6 Lifting *(Zhuang, IHEP)*

1.7 Materials & Compatibility Testing *(Yeh, BNL / Chen, IHEP)*

1.8 Other AD Systems *(Wise, UW)*

1.9 AD Integration *(Heeger, UW / Cao, IHEP)*

1.10 AD Assembly & Installation *(Cherwinka, UW / Cao, IHEP)*

1.11 Subsystem Management *(Heeger, UW / Cao, IHEP)*

*L3's combination of scientists and engineers as needed for subsystems*
Organization, Management, WBS

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*L3*’s combination of scientists and engineers as needed for subsystems

→ Have expanded and strengthened engineering and management team since Jan 08

US L2 deputy
Jeff Cherwinka, UW - USA

Lead Engineer for 1.1.5
Wenman (UW)

AD Assembly&Installation
Cherwinka (UW engineer)

US LS Hall Coordinator&
AD Filling
Wise (UW scientist)

AD Testing and Commissioning
Band (UW scientist)
PMT Mounts and Ladders (WBS 1.1.4)

CD-3b Item

- ladder allows PMT installation after AV assembly
- design is complete, completed FEA
- prototyped PMT mounts
- black radial shield is now part of baseline design

Maximum displacement: 60 µm

Status
- FDR in Apr 2008
- detailed fabrication drawings
- ready for fabrication
PMT Cable Feedthroughs and Drybox (WBS 1.1.4)

CD-3b Item

- cables carrying the signals from the AD PMTs must pass through the walls of tank
- dry box houses this electrical junction
- prototype built and tested in air and under water
- decision on AD PMT cable material in water pool in next 2-3 weeks

Status
- FDR in Apr 2008
- cleared for export
- detailed fabrication drawings
- cable seal assembly procedure complete
- shipped seals to Hamamatsu for PMT cable assembly
- ready for fabrication
Gd-LS Production (WBS 1.1.3)

CD-3b Item (joint scope between PRC and US)

Production of 200 ton Gd-LS (0.1% Gd, yield 70%) requires 680Kg GdCl$_3$.6H$_2$O.

- Design of production equipment completed in Apr 08. (PRC)
- Initiated small scale test runs to observe the needed adjustments and modifications
- IHEP started installation of production site in Apr 08 (PRC)

Finalizing....
- storage of Gd solid
- water content and its impact
- filtration after mixing
- mixing scheme

Status
- FDR for solid production in Apr 2008
- equipment test runs in Jun 08
- test run for mass solid production in Jul 08
- real-scale test run for 4-t mixing in Aug 08
- FDR for solid dissolution in Jul 08
AD Filling System & Target Mass Measurement (WBS 1.1.5)

CD-3b Item

Gd-LS

LS

MO

Filling and Target Mass Measuring in Hall 5

Status
- PDR completed in Oct 2007
- detailed design in progress
- ISO tank RFP issued in June 08
- FDR of complete system in Aug 08

load cells
accuracy < 0.02%

Coriolis mass flowmeters
< 0.1%

Filling probe

pumping station with flow meters

For food, beverage, pharmaceutical and chemical applications!
Overflow Tanks, Calibration Tubes, Gate Valves (WBS 1.1.5)

CD-3b Item

- off-center calibration tubes
- central overflow tank system
- calibration boxes
- central overflow tanks
- calibration tubes

Status
- detailed design in progress
- FDR of complete system in Aug 08
CD-3b Item

LS level sensors, 2 types (capacitance, ultrasound)

Gd-LS level sensors, 2 types (capacitance, ultrasound)

MO level sensors, 2 types (capacitance, ultrasound)

Gd-LS visual level monitor (CCD)

Target Mass Monitoring

Identified and tested liquid level sensors
- ultrasonic
- pressure
- capacitance

→ sensors good to < 0.05% of total target mass

N2 Cover Gas System

Status
- PDR in Oct 2007
- detailed design in progress
- FDR of complete system in Aug 08
AD Assembly & Installation (WBS 1.1.10)

CD-3b Item

formal assembly procedures

<table>
<thead>
<tr>
<th>Physical Sciences Laboratory</th>
<th>PSL TN-2008-01</th>
</tr>
</thead>
<tbody>
<tr>
<td>University of Wisconsin-Madison</td>
<td>Date: May 30th, 2008</td>
</tr>
</tbody>
</table>

**Title:** PMT Feedthrough Plug to PMT Cable Assembly Procedure

**Author:** Jeff Cherwinka

Abstract:

Daya Bay Project Procedure

integration and installation plans (together with WBS 1.7)

image courtesy of R. Brown

assembly sequence

Status

- developing assembly and installation plans with formal procedures
- PDR in Aug 2008
- FDR in Oct 2008
ISO Tank for Target Mass Measurement (WBS 1.1.5)

CD-3a Item

25,000L Teflon-lined/coated ISO tank

Status
- PRR in May 2008
- cleared for export
- RFP issued on June 4, 2008
- procurement process in progress
- bids due on June 25, 2008

Standard 20” manlid and breather port

(1) 2” Port for filling
(1) 2” Port for monitoring
(1) 2” Port for discharging on top

(2) 1” N2 ports on top near each end
Chemicals for Liquid Scintillator Production (WBS 1.1.3)

**CD-3a Item**

**Carboxylic acid (THMA)**
- Specifications complete and reviewed
- Finished contract with selected vendor
- Cleared for export; import duty (China) & loan-agreement (US-China) pending
- Surveyed available purification agents in US and China, with option of self-operation. May perform purification in US.
- 4-week lead-time

**GdCl\textsubscript{3}**
- Specifications complete and reviewed
- Initiated contract with selected vendor, procurement in progress
- Selection of purification equipment by end of June
- Cleared for export; import duty (China) & loan-agreement (US-China) pending
- Chemical plus equipment procurements, 6-week lead-time

**Status**
- FDR in Feb 2008
- Chemicals cleared for export
- Quotes in hand
- Procurements in progress or placed by end of June

Target procurement date 6/30/08
AD Photomultipliers (WBS 1.9)

CD-3a Item

AD PMT Testing
- 100% sample burn-in and test
- random sample fraction for additional tests (glass radioactivity, etching, pressure, etc)
- dark boxes complete, 1st at UCLA for integration testing

AD PMT System
- PMT assembly with base, potting, and RG-303 cable (no additional work by collaboration)
- use splitter module to decouple AC power & DC
- AD PMT high voltage system will use CAEN SY1527LC and A1932 modules
- High voltage slow controls will be based on the previous designs at STAR and IHEP

Status & Delivery Schedule
- Hamamatsu PMT assemblies selected for ADs
- Delivery based on Hamamatsu schedule & matched to RLS
- Off critical path (by a month or more)
- First PMT’s will show up in June
Acrylic Vessel System (WBS 1.1.2)

CD-3a Item

Pair of nested acrylic vessels

3m vessel

4m vessel

Calibration pipe connections

Lids

Ribs and support structure

Support and hold-down mechanism

FEA analysis of worst case scenario:
Uneven filling

Status
- PDR in Jul 2007
- FDR in Dec 2007
- PRR in Feb 2008
- Completed prototype vessel and lid
- Contract with Reynolds being finalized
AV Prototypes (WBS 1.1.2)

4m Vessel Prototype at Reynolds in CO, USA

3m Vessel Prototype at Nakano, in Taiwan

dimensional QA on both vessels
Response to CD-2/3a Recommendations

Acrylic Vessels

1. Finalize and review the technical specifications for the acrylic material.
2. Complete and review the qualification procedures for the acrylic material.
3. Finalize and review the technical specifications for the AVs.
4. Complete and review the fabrication procedures for the AVs. The quality assurance/quality control procedures for vessel fabrication should reflect the existing RPT procedures and the project specific procedures.

   → held PRR in Feb 08
   → integrated QA plan into fabrication document (phone meetings and on-site visits with Reynolds, modified QA plan based on prototype experience)
   → developed quantitative QA methods for transmission and stress measurements

Liquid Scintillator

1. The project should be approved to procure the carboxylate and pursue the most suitable method of purifying it. Likewise, regarding the gadolinium chloride, the project should be approved to procure and purify it, if needed, in the way it sees fit consistent with the baseline and contingency.

   → held FDR in Feb 08
   → developed final specifications
   → ready for procurement
Developed Quantitative QA Program and Fabrication Plan
(in response to CD-2/3a review recommendations)

AV stress measurements

Transmission measurements

long-term acrylic stress limits: < 5MPa
sensitivity of optical stress measurement: ~ 0.06MPa
require > 90% transmission from 350-550nm
Status of Cost, Schedule, and Other Issues

- Increase in cost of raw UVT material for AV and small changes in AV flange design since Nov 2007 resulted in re-negotiation of AV contract. Price increase from $176k → $207k per vessel.

- ~2 months delay in setting up subcontracts and in finalizing contract with Reynolds. Delivery of first 2 AVs by end of 2008 still possible.

- AV prototype lid broke during handling by Reynolds. Review of AV lid incident and review of lid design in progress. Will take some time. Prototype lid was not final design. In the meantime, we can procure raw acrylic material (4-6 weeks), fabricate tooling (~4 weeks), form panels for vessel body, etc...

- Scaling up Gd-LS production process will proceed in steps. Several test runs soon. 4-ton mixing test scheduled for Aug 08. Still within schedule.

- Additional specialized AD tooling and personnel equipment is being considered for AD assembly&installation.
AV Lid Prototype Incident

Breaking of 4m AV Lid During Movement at Reynolds

- acrylic lid broke apart suddenly while it was sitting on top of the vessel.
- it was being moved by Reynolds workers to align the holes but at the time of the break little or no pressure was being applied to it.
- a temporary wooden lifting beam was hanging from central calibration port

Likely Cause
- non-conforming bond at central port (failed visual inspection of Reynolds QC team)
- additional load from lifting beam, no radial constraint of lid?
- old lid design? current lid design reviewed at PRR is stronger.

Lessons Learned
- need strict reporting of non-conforming bonds/part/procedures by Reynolds to Daya Bay project
- need to use the same lifting and handling techniques at Reynolds as at Daya Bay (special fixtures etc)
- analysis of incident ongoing... will prototype second 4m lid after considering redesign
- will also review 3-m lid design
Schedule and Milestones

- CD-2/3a review: Jan 08
- start fabrication of acrylic vessels #1,2: Apr 08 (Jun 2008)
- complete chemical procurement for Gd-LS and LS: Jul 08
- PMT mounts and ladders at Daya Bay: Dec 08
- acrylic vessels #1, 2 delivered to Daya Bay: Dec 08
- mixing of LS and Gd-LS begins in LS Hall: Jan 09
- target mass system installed in LS Hall: May 09
- LS Hall ready for AD filling: May 09
- complete assembly of AD #1,2: May 09
- complete filling of AD #1,2: Jul 09
- Daya Bay near site ready for data taking: Nov 09
- complete assembly of AD #3,4: Sep 09
- complete assembly of AD #5,6: Dec 09
- complete assembly of AD #7,8: Jun 10
- Ling Ao near site ready for data taking: Jul 10
- Daya Bay far site ready for data taking: Dec 10

still feasible
Summary

- Design of Antineutrino Detector System is well advanced, FDRs and PRRs for most detector elements.
- New instrumentation and detector elements have been tested in the lab. Detailing and completing final designs. Expect to complete reviews of final designs for entire Antineutrino Detector in Aug 2008.
- Developed quantitative QA program for AV.
- Strengthened AD science and engineering team with senior personnel, starting to plan for assembly and commissioning.
- Have begun procurement of long lead items
  - ISO tank RFP issued, procurement in process.
  - Gd-Cl, TMHA, and purification equipment ready for procurement. Awaiting customs clearance. Loan agreement between BNL and IHEP not yet approved by DOE. TMHA may be purified in the US.
  - Detailed QA and fabrication plan for AVs. AV contract close to final, AV lid incident under investigation.

→ Ready to start fabrication of AD subsystems
CD-3b Item

- Program focuses on
  - Impacts of material to liquid; UV-Vis, gamma low-background counting
  - Impacts of liquid to material; XRF, ICP-MS

- Aging tests as a function of time
  - 40°C for Gd-LS and LS
  - 70°C for water

- Since 2007 over 150 materials (polymers, SS, coating, liners, etc.) from different sub-systems (AD, calibration, PMT, etc.) have been tested in liquids.

- Goal to establish a material database that tabulates compatibility as % deterioration per day

Status

- R&D activities in progress
- Program ready to scale up for materials screening during fabrication