Update on HAWC Optical Calibration System

John A.J. Matthews and W. Miller (**UNM**)

Brenda Dingus (**LANL**)

Petra Huentemeyer (**MTU**)

johnm@phys.unm.edu

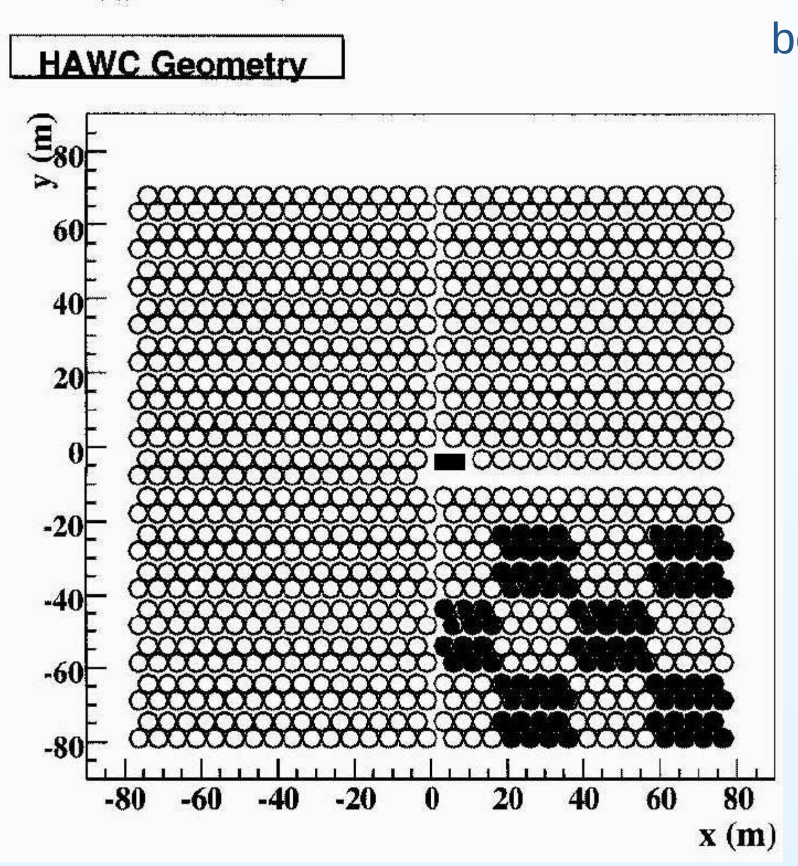
University of New Mexico

Albuquerque, NM 87131

Calibration system: *design goals*

- The primary goal of the HAWC optical calibration system is to monitor the time stability of the HAWC photo-multipliers (PMTs):
  - For optimal event reconstruction, signal times need a relative (across the array) uncertainty of $\lesssim 1$nsec.
  - Thus channel to channel timing drifts and/or slewing corrections must be monitored, and corrected, to meet this timing requirement.
- The secondary goal is to provide light pulses over a range of intensities: from near PMT single photo-electron (PE) threshold to ~ 1000 PEs. This is done using a filter wheel and neutral density filters at the (laser) light source.
- Finally the system should be robust, easy to use and to maintain.

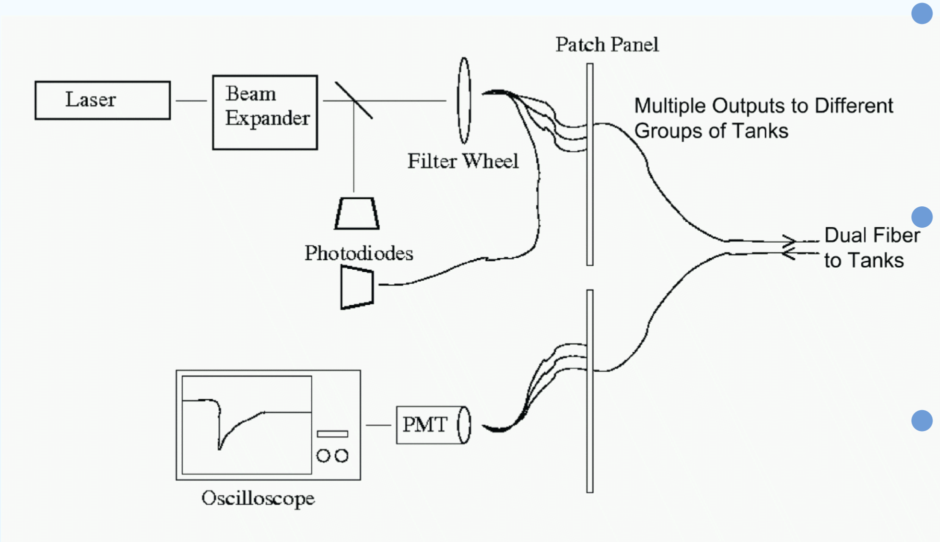
Calibration system: *proposed design*



For various (practical and redundancy) reasons, the tanks are divided into two groups that in space are analogous to the black and white squares of a chess board:

- The **sketch** shows a **sub-set of the HAWC tanks** divided into optical calibration black and white squares of tanks.
- Each square has $\sim 2\%$ of the PMTs; for 5m tanks this corresponded to 16 (4 $\times$ 4 array of) tanks.
- **One laser (and optical distribution system) is used to pulse all of the *black* tanks; a second system pulses all the *white* tanks.**
- The lasers and associating monitoring instrumentation will be located in a temperature controlled *calibration enclosure* [half-length shipping container] at the *center* of the HAWC array.

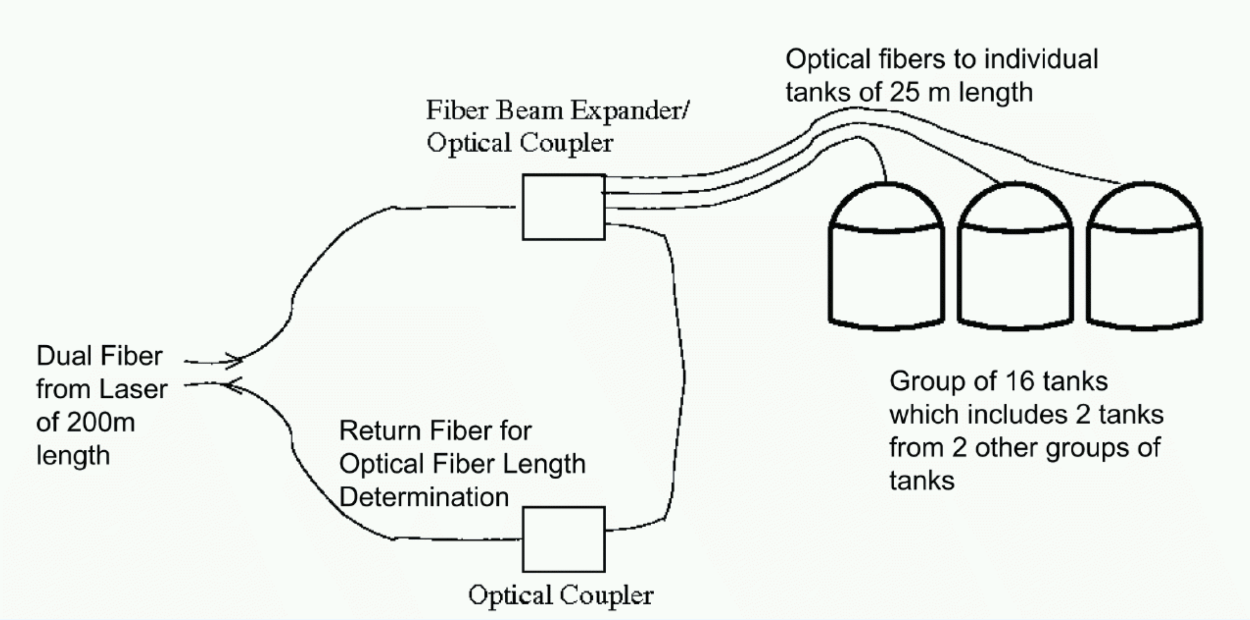
Calibration system: *light source(s)*



Sketch of proposed light source and associating monitoring instrumentation:

- One (of two total) laser light distribution systems is **sketched.**
- 1:37 optical splitters fan-out the laser light pulses to the ~ 32 paths to the centers of all black (or white) squares of tanks.
- Duplex, $\lesssim 200$m *long*, 62.5/125 μm graded index fi bers provide **both out-going and return light paths** to/from the squares.
- Return light pulses are merged using 4 19:1 optical fan-ins: one for each quadrant of the array.
- To the different "return light pulses" we add a relative timing delay (in increments of ~ 5m optical fi ber) to allow eachsquare to be monitored simply.

Calibration system: *field distribution*



Sketch of proposed field distribution:

- At the center of each square the light is split (further) to be routed on *short* (~ 25m) fibers to each tank.
- Each square will distribute light to the tanks in the square $+$ a *loop-back* fiber for monitoring $+$ to ~ 1 tank in adjacent squares (**to link the timing of black and white squares**).

Calibration system: *recent studies*

- What is the fiber to fiber uniformity and light coupling efficiency of the *PowerChip NanoLaser* plus $\sim 5\times$ beam expander into the 1:37 optical splitters (at the light source)?

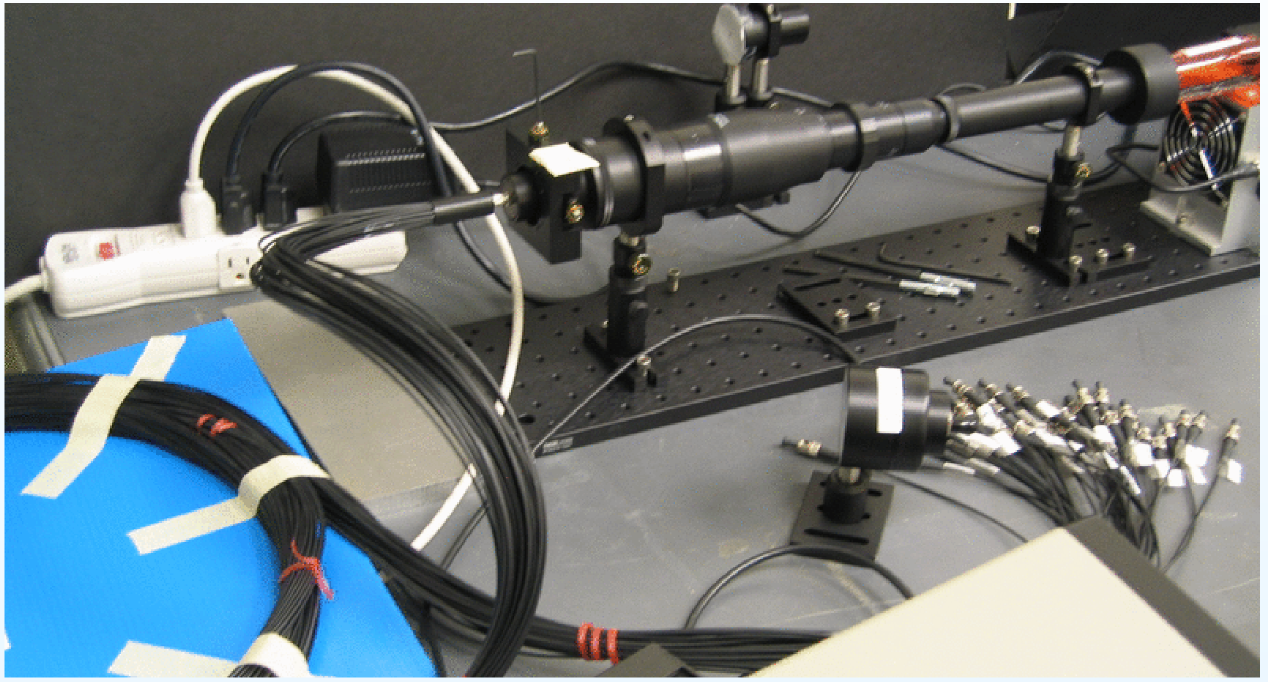
- What is the fiber to fiber uniformity and light coupling efficiency of the 62.5μ*m fiber + ThorLabs optical lens* into the 1:17 optical splitters (at the field distribution)?

- What are the possible *optical diffusers* for illumination of the PMTs in each water Cherenkov tank?

- What is the expected light intensity at the PMTs for the proposed calibration design?

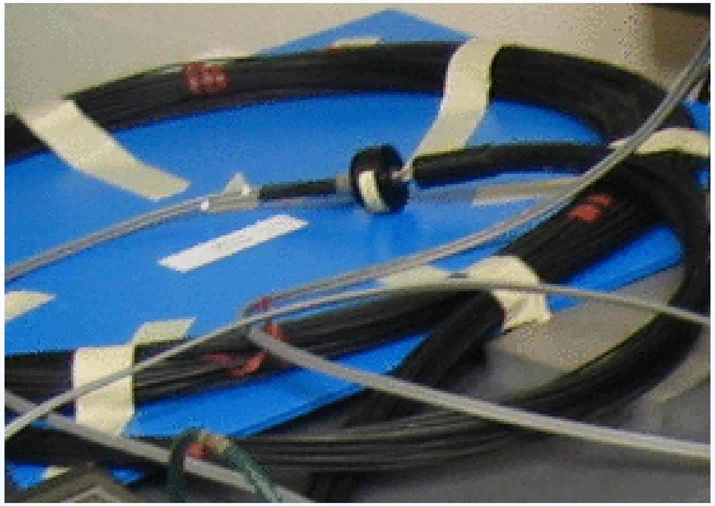
- Are there any issues with the proposed monitoring of the individual squares of tanks?

Calibration system: *source distribution*



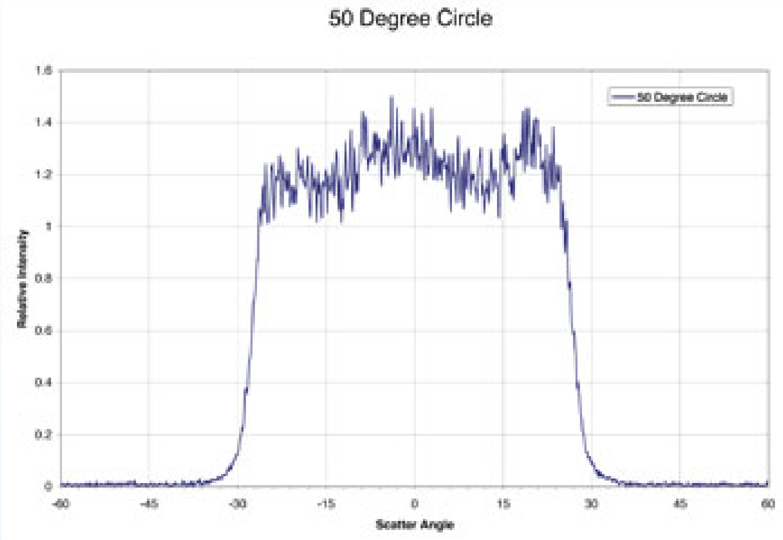
- $5\times$ beam expanding results in rather uniform illumination of the 1:37 optical fiber splitter.
- Typical signals are ~ 15nJ/pulse [± 25%]; the nominal laser energy is 26μJ/pulse (using a LaserProbe Rm6600A radiometer with RjP-465 silicon sensor.)

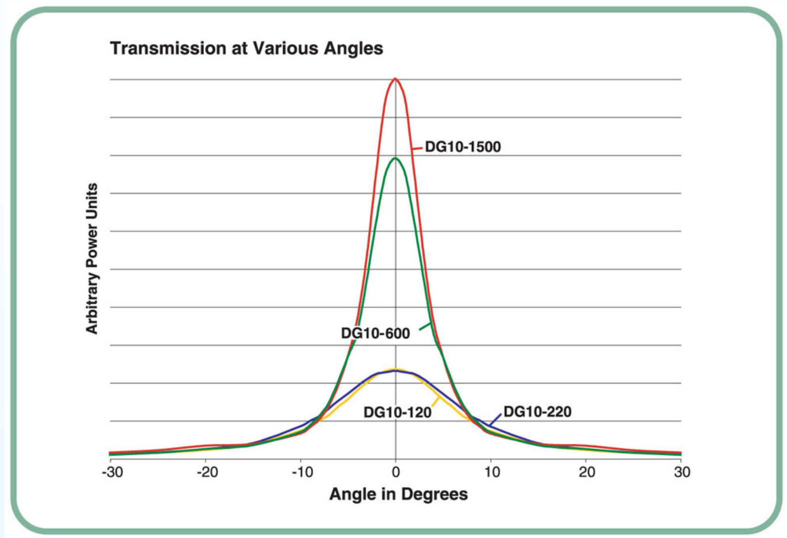
Calibration system: *field distribution*



- Use ThorLabs aspheric lens ($f_L = 4.5$mm) to create a parallel beam (from the fiber) into the 1:n optical fiber splitter.
- But speckle pattern (from fiber) means that we must add an optical diffuser (between the lens and the 1:n splitter).
- Thus net signal ... after all components ~ 0.75pJ/pulse [± 40%] at output of field distribution: $\sim 0.2\times$ for ST:ST couplers **plus** 300m (total) length of fi ber AND $\sim 0.25 \times 10^{-3}$ for the fi eld splitter.

Calibration system: *tank diffusers*





- For 7.2m tanks with 3 PMTs: do we use one (common) diffuser or three (1/PMT)?
- If one: then we probably need at a minimum 200μm fibers (from the field splitter) and a combination of ThorLab: engineered ($50°$) and 600-grit diffusers.
- If three: then we can use 62.5μm graded index fibers everywhere with a simpler ThorLab: 120-grit diffuser.

Calibration system: *PMT signal estimate*

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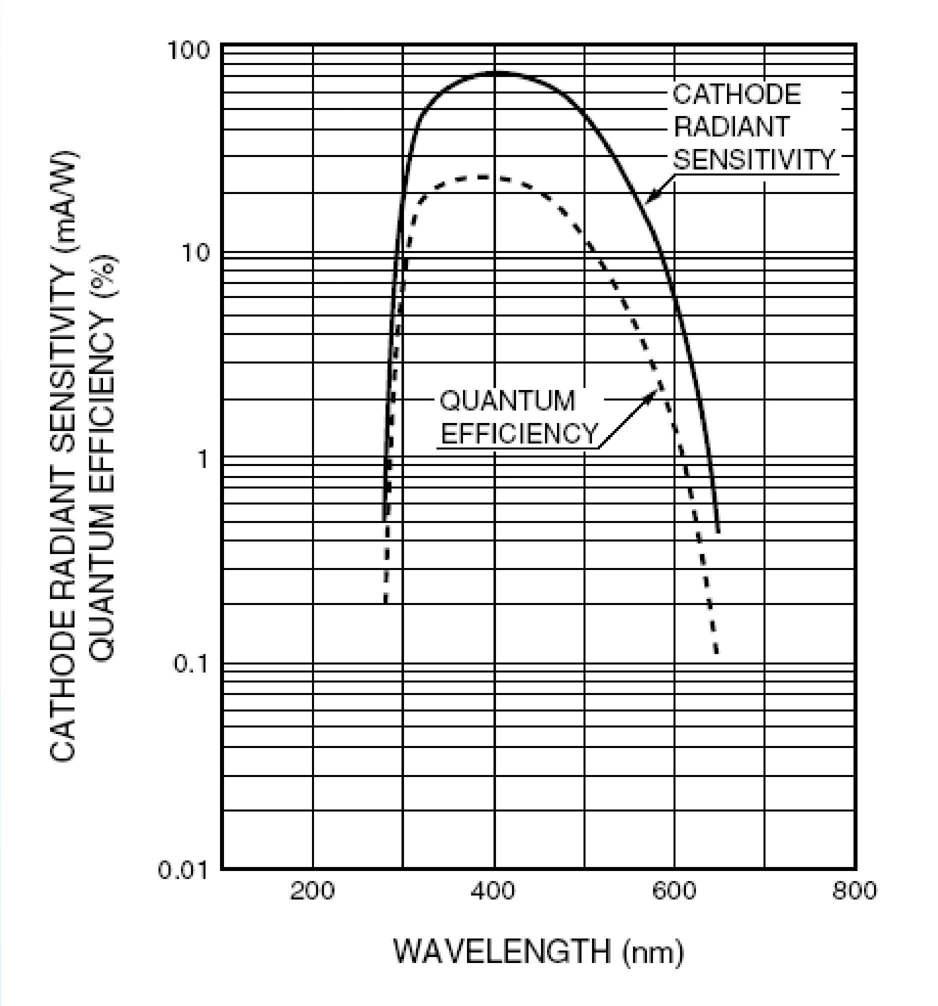
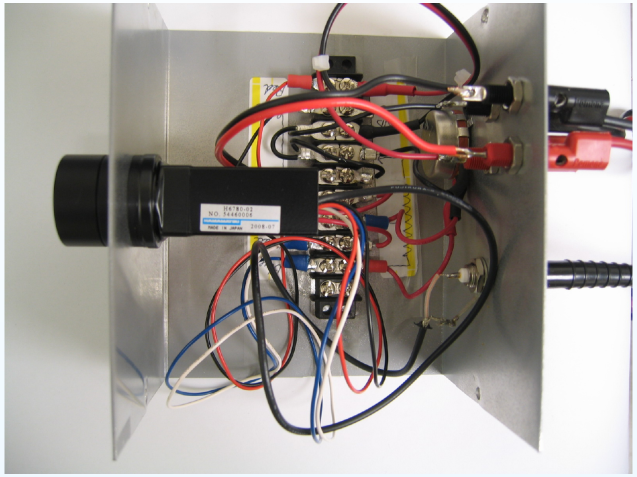


- 0.75pJ/pulse at the tank is $\sim 2.0 \times 10^6$ 532nm photons
- If the PMT accepts 1% of the calibration light and assuming a $\sim 6\%$ PMT Q.E. then we expect ~ 1200 photo electrons (P.E.s). (The design goal is 1000.)

Calibration system: *PMT R/O of 3 squares*

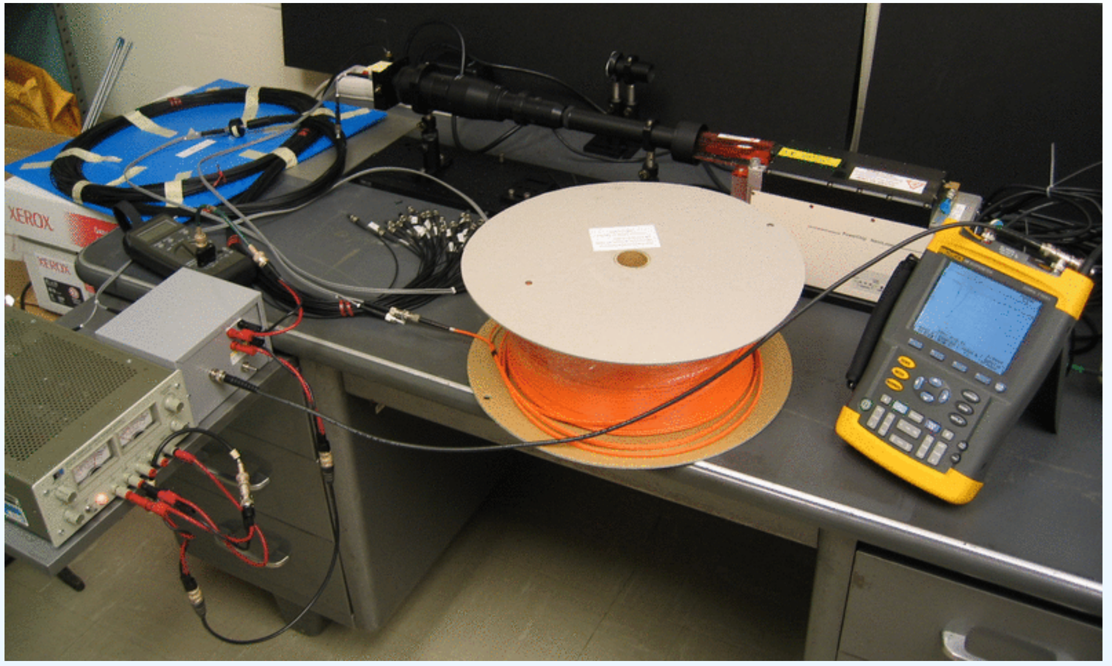


We use Hamamatsu H6780-2 photon detectors to monitor the return light from the squares of tanks (above photo)

5m optic fiber "delays" have been added between the return light from **three** representative squares of tanks (Right top)

The observed time difference for 5m of 62.5μm graded index fiber is 25.6ns (Right bottom)

Calibration system: *summary/conclusions*



- A “table-top” realization of the proposed HAWC optical calibration system allows a detailed evaluation of the HAWC PMT and monitoring signals.
- No “show stoppers” have been found; however the maximum predicted HAWC PMT signals strongly encourage the one diffuser/PMT option in the tanks.