Mechanical Performance of Large Format Underwater Photomultiplier

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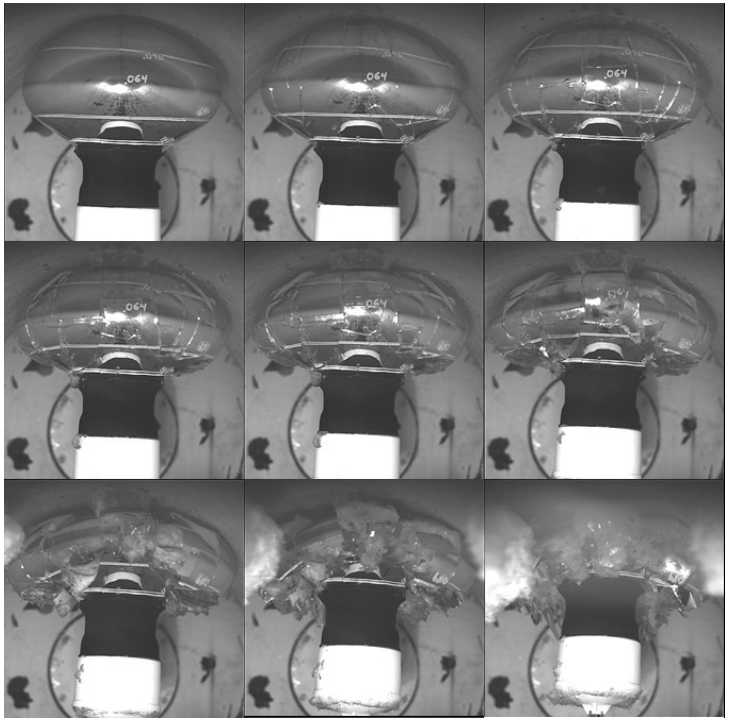
BROOKHAVEN NATIONAL LABORATORY

Introduction

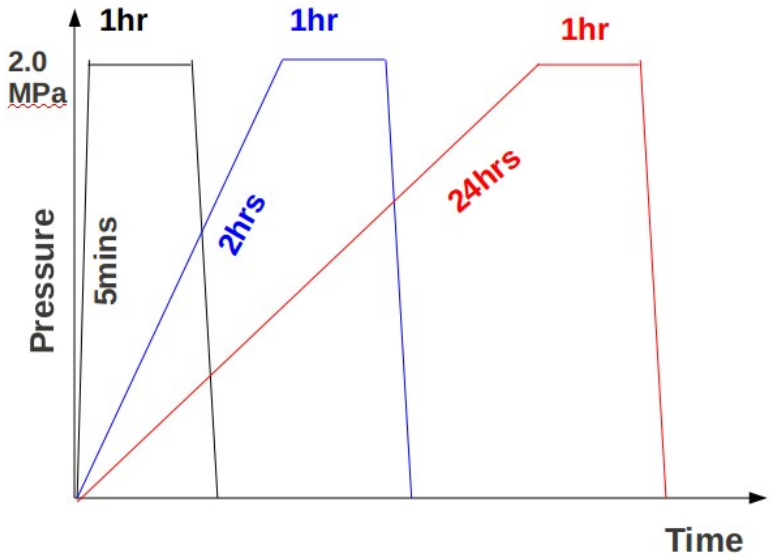
- Mechanic performance of large format semi-hemispherical photomultipliers (PMTs) is critical for the large water cerenkov detectors.
  - Determine if the PMT can withstand expected hydrostatic pressure and potential shock waves in the water
  - Improving the PMT deployment to mitigate the risk of chain reaction.
- PMT hydrostatic pressure test
- PMT underwater implosion test
  - Single PMT implosion test
  - Multiple PMTs cascade implosion test
  - PMT assembly configuration test
- PMT implosion simulation

PMT Hydrostatic Pressure Test

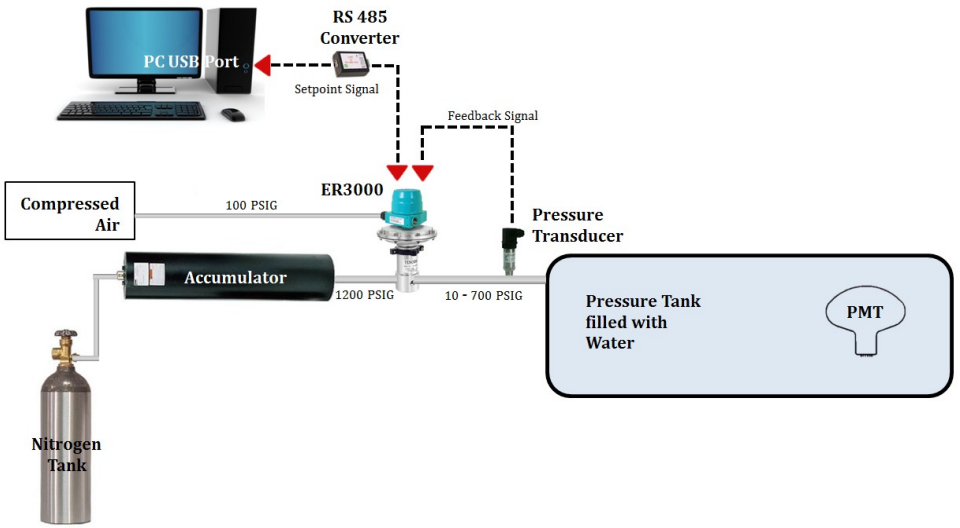


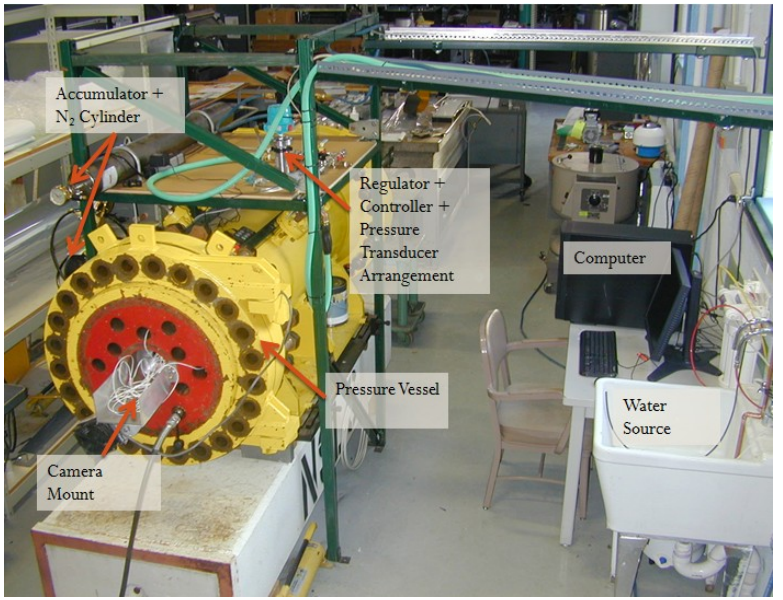
Slow Rise Pressure Test

- Goal: Check the performance of glass under slow rise pressure conditions.
  - How much strength of glass decreases (changes) if we rise the hydrostatic pressure slowly.
  - This will help us decide the correct pressure rating of PMT glass.
- Hydrostatic pressure tests:
  - Multiple types of PMTs
    - Hamamatsu 10”
    - ETL 11”
    - Hamamatsu 12” PMTs
  - 5 mins / 2 hrs / 24 hrs each
  - Maximum 2MPa



BNL Slow Rise system





Pressure slow rise system:

- BNL pressure vessel tank (189 L, up to 2.4 MPa)
- High speed camera (Photron, 6000 FPS)
- High pressure accumulator feed in (11 L, up to 14 MPa)
- ER3000 electronic pressure controller
- Regulator / transmitter feed back
- Automated pressure rising function controlled by LabView

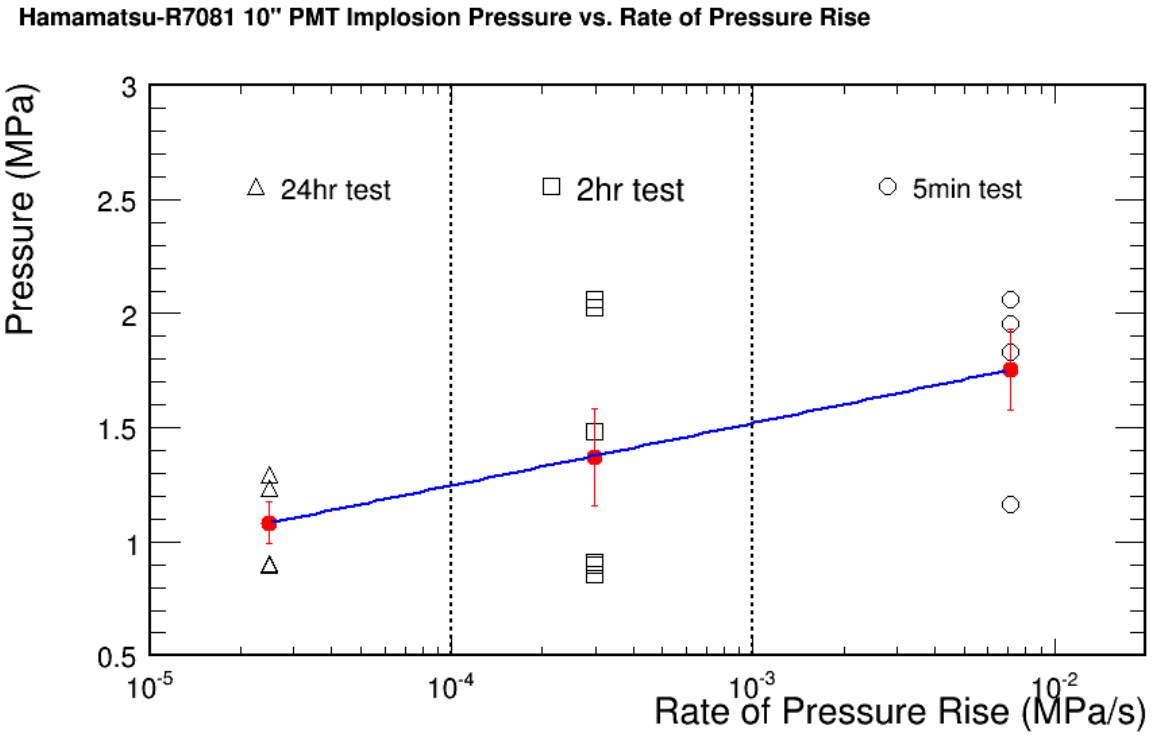
Slow Rise Pressure Tests

✗ 14/19 10” Hamamatsu R7081 PMT failed.

✗ 5/13 11” ETL PMT failed.

✔ All 45 12” Hamamatsu R11780 PMT passed the test.
➔ Some PMTs were tested for each loading rate

★ *Hamamatsu 12” PMT has a better mechanical performance, should have rating of 2MPa (20bar).*

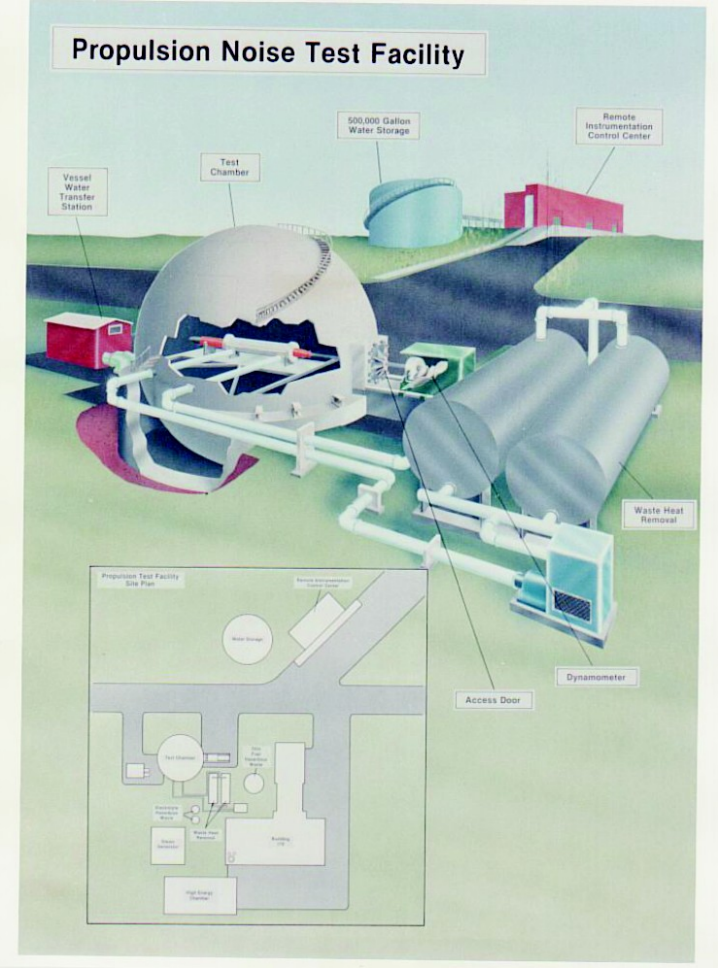


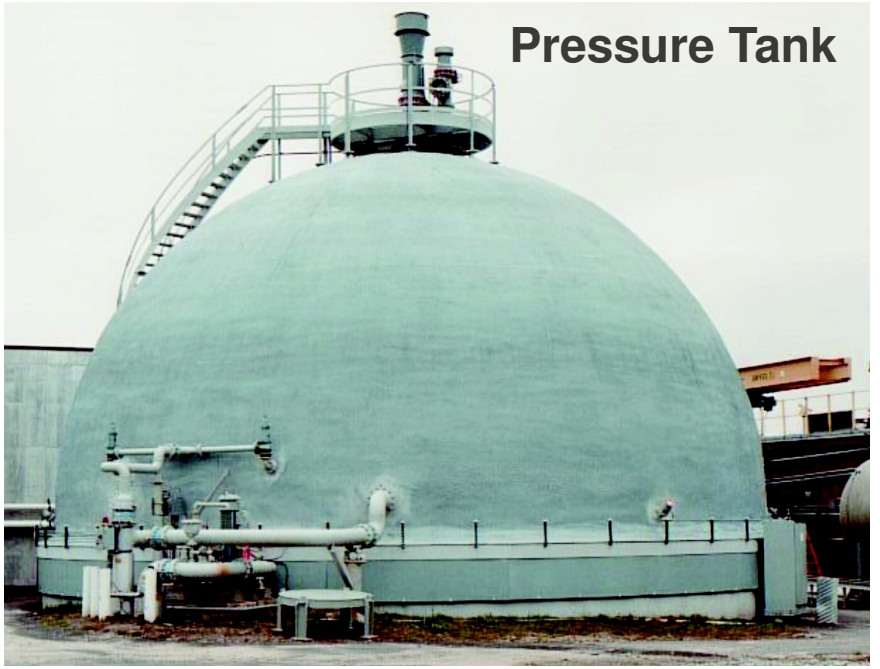
➔ The PMT withstanding pressure is proportional to the logarithm of the rate of water pressure rise.
➔ Schott/SNO rule: Testing at twice the pressure for 1 hour is equivalent to 20 years at normal pressure.

PMT Underwater Implosion Test

Navy Undersea Warfare Center (NUWC) Facility

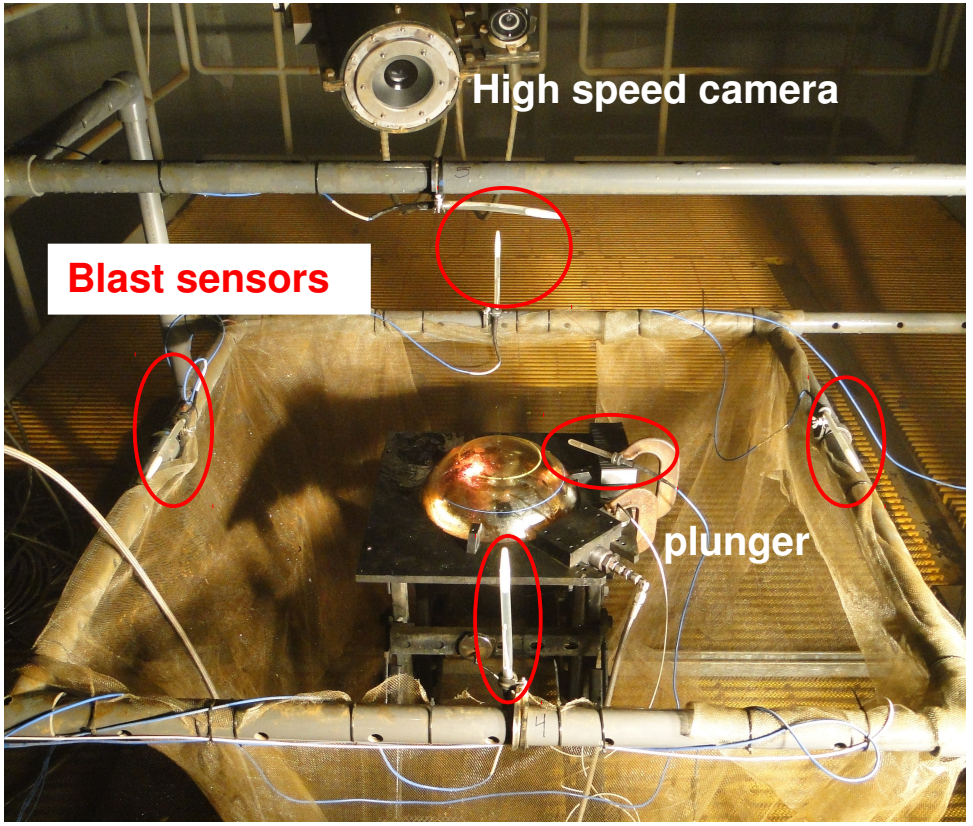
The 50Gallon BNL pressure tank is too small to create the same shock wave pattern as the real detector.

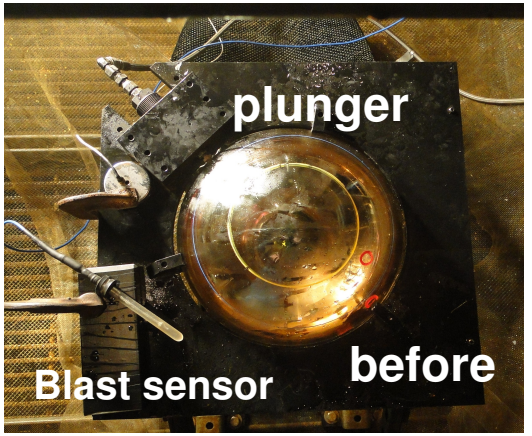


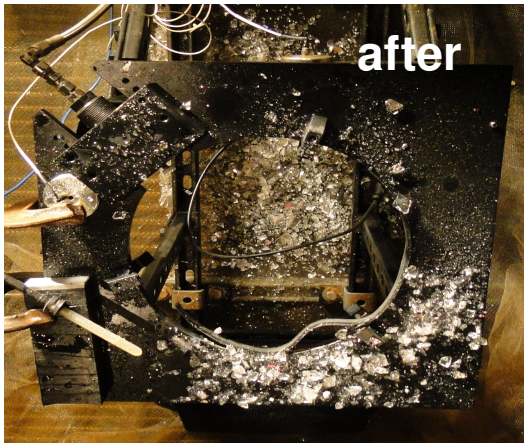


- Cooperation between BNL and NUWC through Cooperative Research And Development Agreement (CRADA)
- 15m diameter / 500,000 gallons of water
- Rated of 110 psi hydrostatic pressure at the center

Bare-PMT Implosion Setup

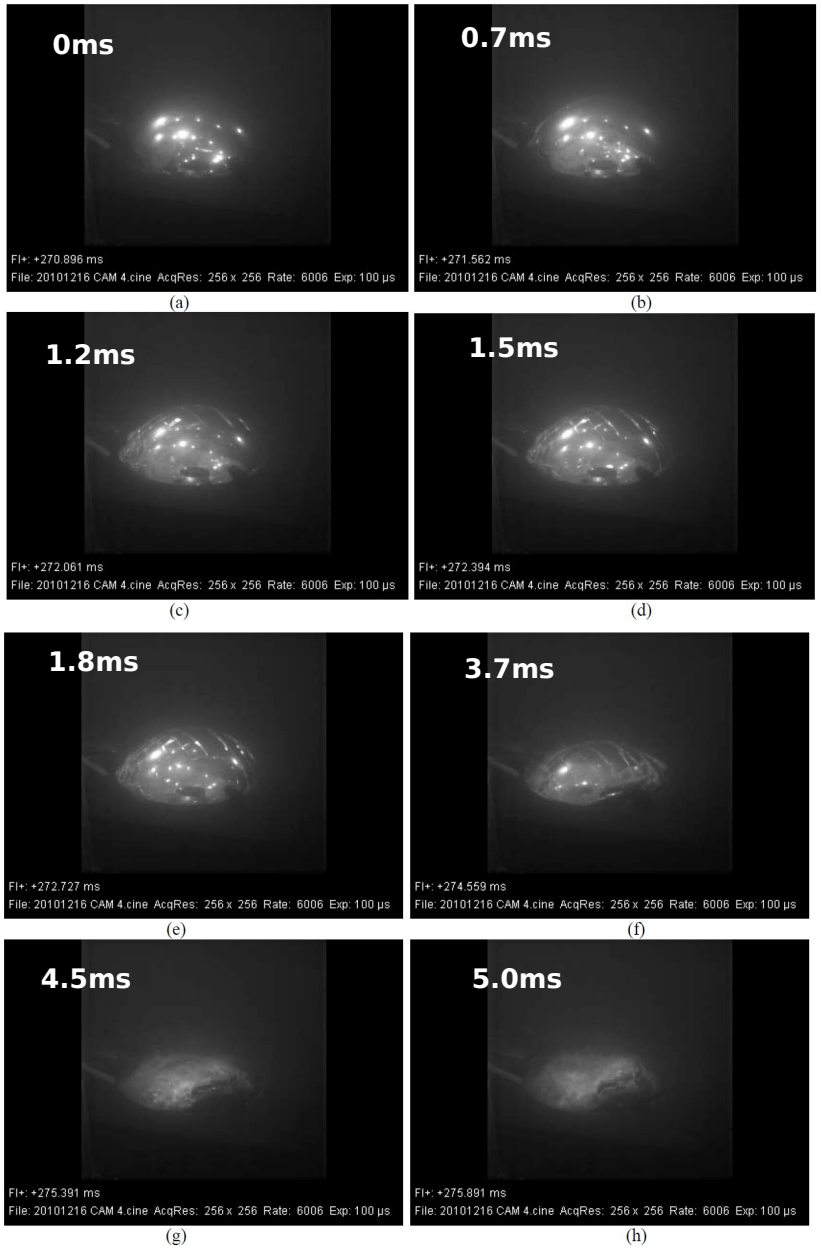


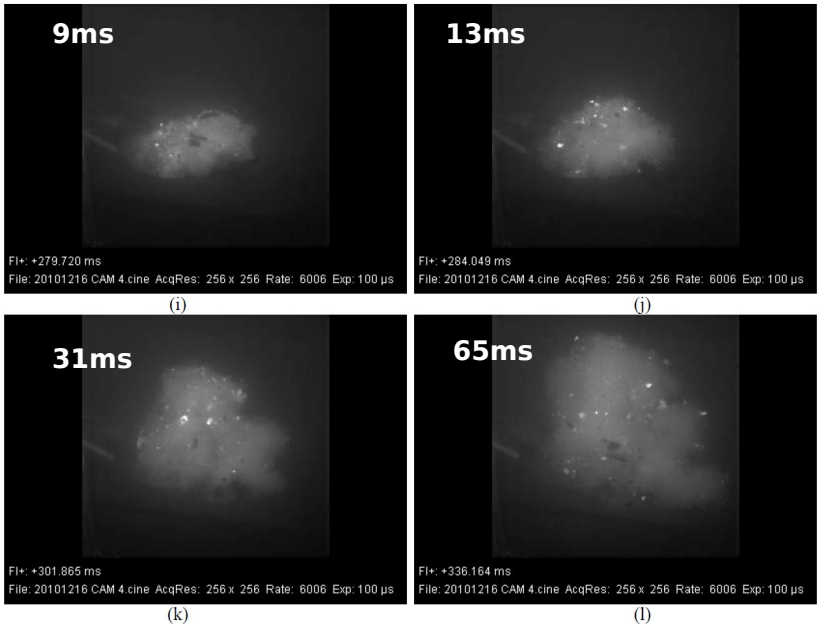




- Hamamatsu R7081 10” PMT manual forced implosion at 0.6MPa hydrostatic water pressure
- 7 PCB ICP Water proof pressure sensors
- 2 High speed cameras (6000 FPS)

Bare-PMT Test Screen Shots



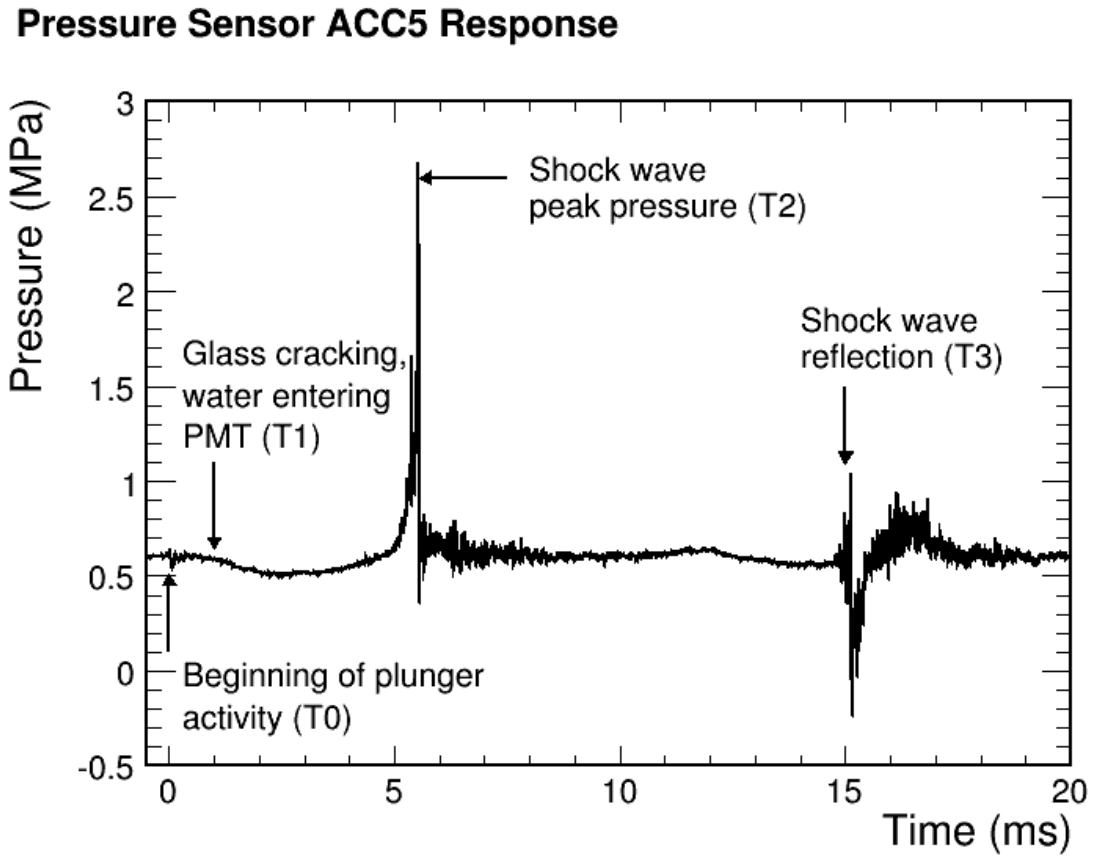


0-1ms: crack initialed by plunger

1-4ms: “grid” crack pattern formed on the PMT and symmetric collapse.

5ms: shock wave formed and start propagating.

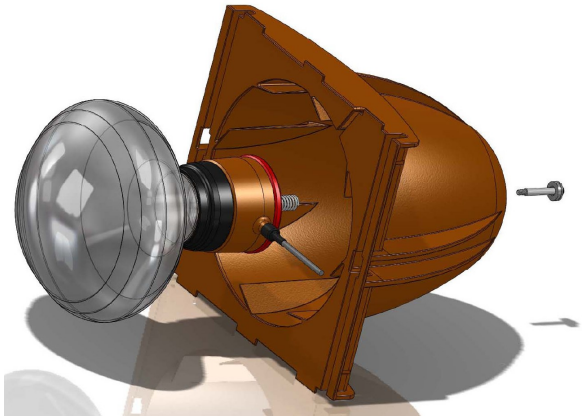
Blast Sensor Pulse Structure



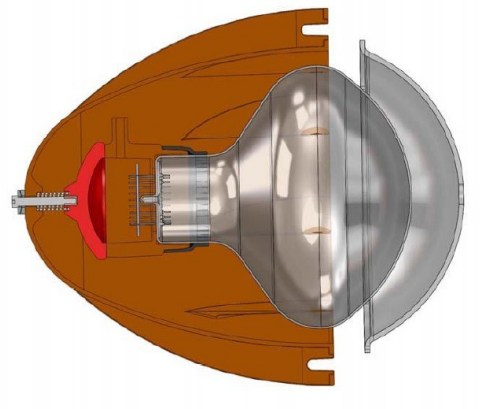
- Glass cracking time:
  - T1 – T0 ~ 1.0ms
- PMT crushing time:
  - T2 – T1~ 4.5ms >> 0.8ms (sound traveling time)
- Shock wave spreading time:
  - T3 – T2 ~ 10 ms (1497m/s ~ speed of sound in water at 25℃)

D.Milind et. al. *"Underwater Implosion of Large Format Photo-multiplier Tubes"* NIM. A. 670 (2012) 61-67 *Doi: 10.1016/j.nima.2011.12.033*

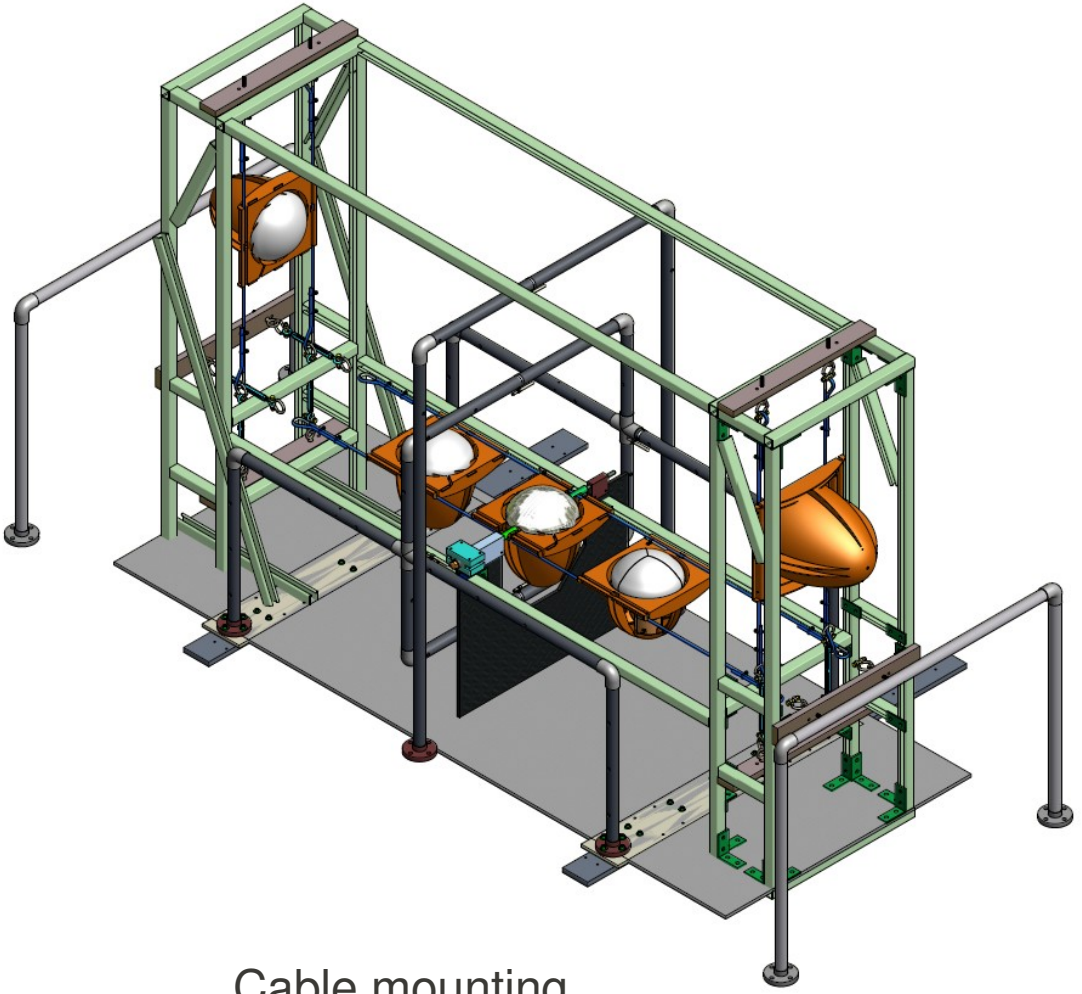
PMT Assembly Designs



Open-housing

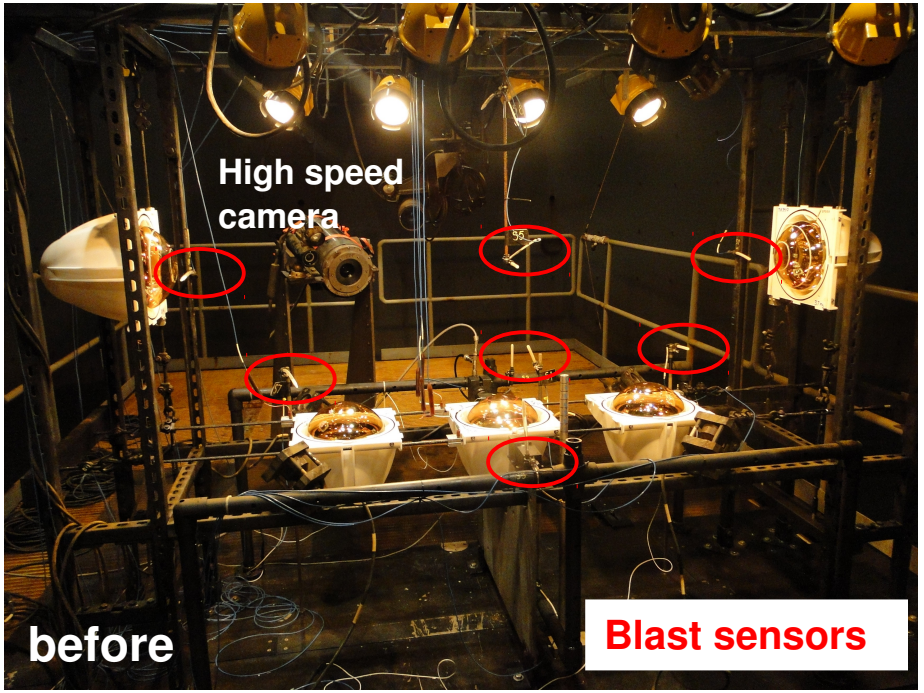


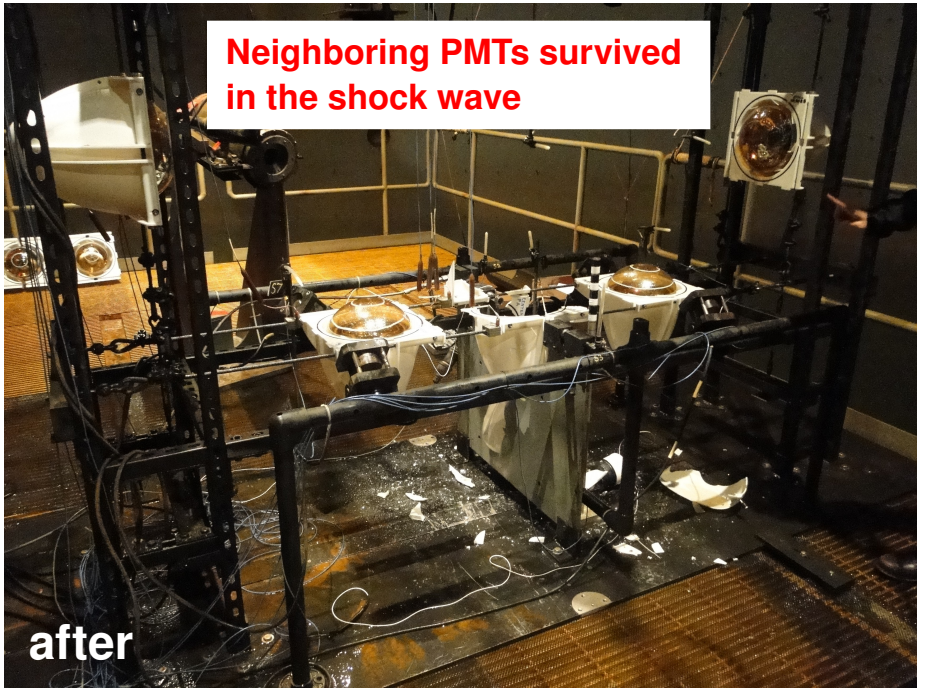
Closed-housing

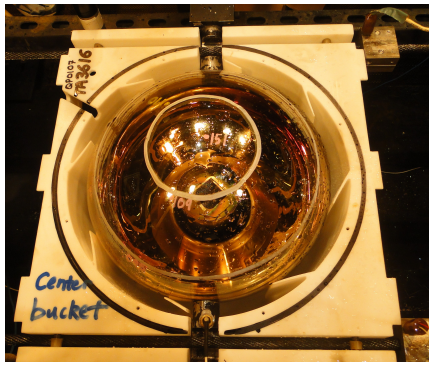


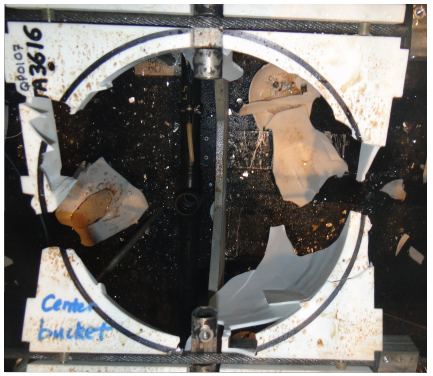
Cable mounting

Multiple PMTs Cascade Test Setup



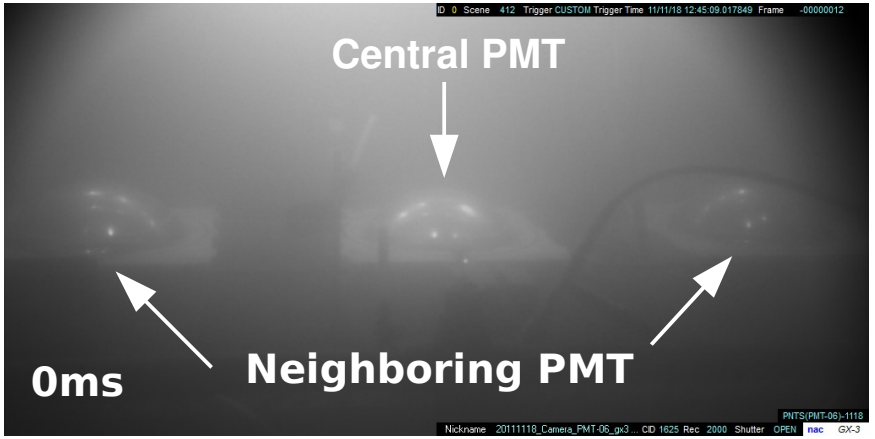






- 5 10” Hamamatsu R7081 tubes with protective housing under 0.6 MPa water pressure
- Tubes are mounted on cables and separated by 50cm from center to center.
- 2 High speed cameras (4000FPS and 2000FPS)
- 8 Water proof pressure sensors
- 9 accelerometers are installed on the cables

Open-housing Test Screen Shots



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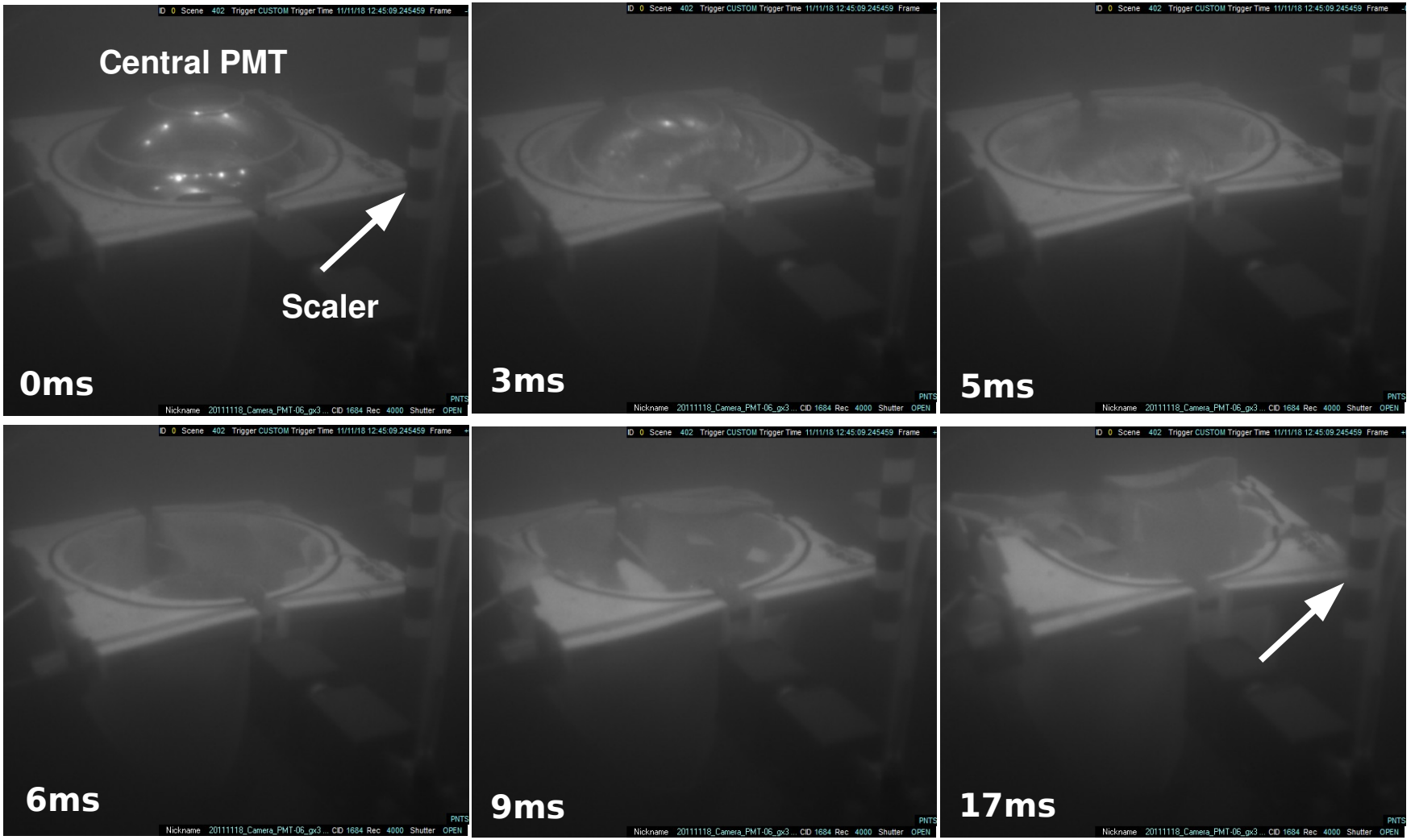
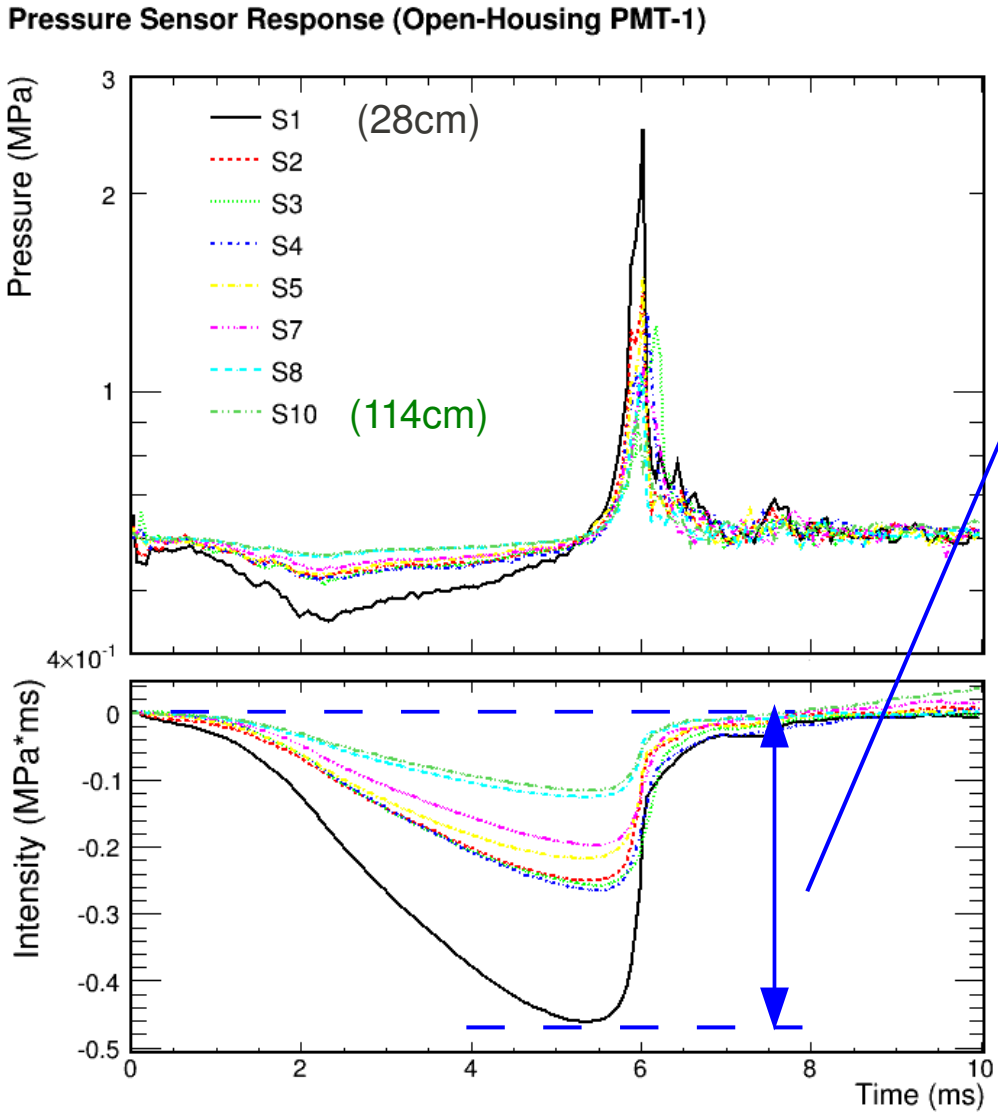
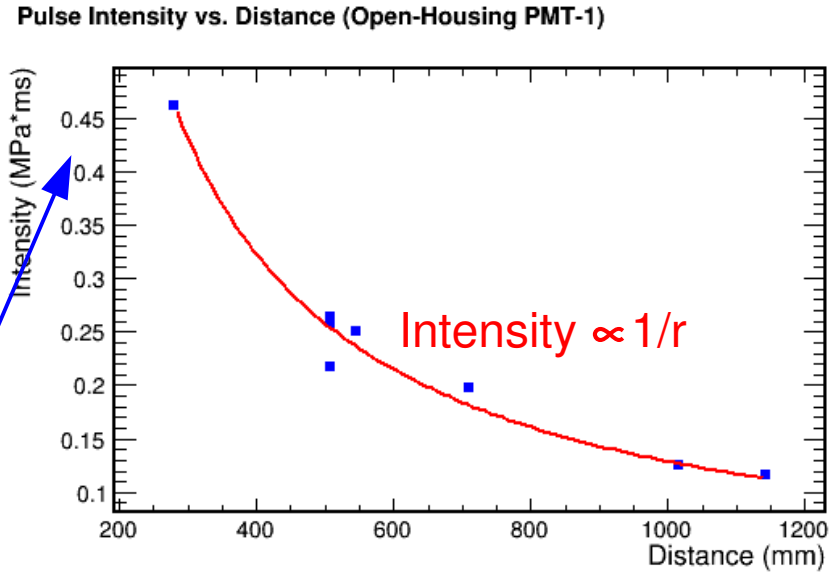


Cable moved up by ~ 1 inch

Characteristics of the Shock Wave

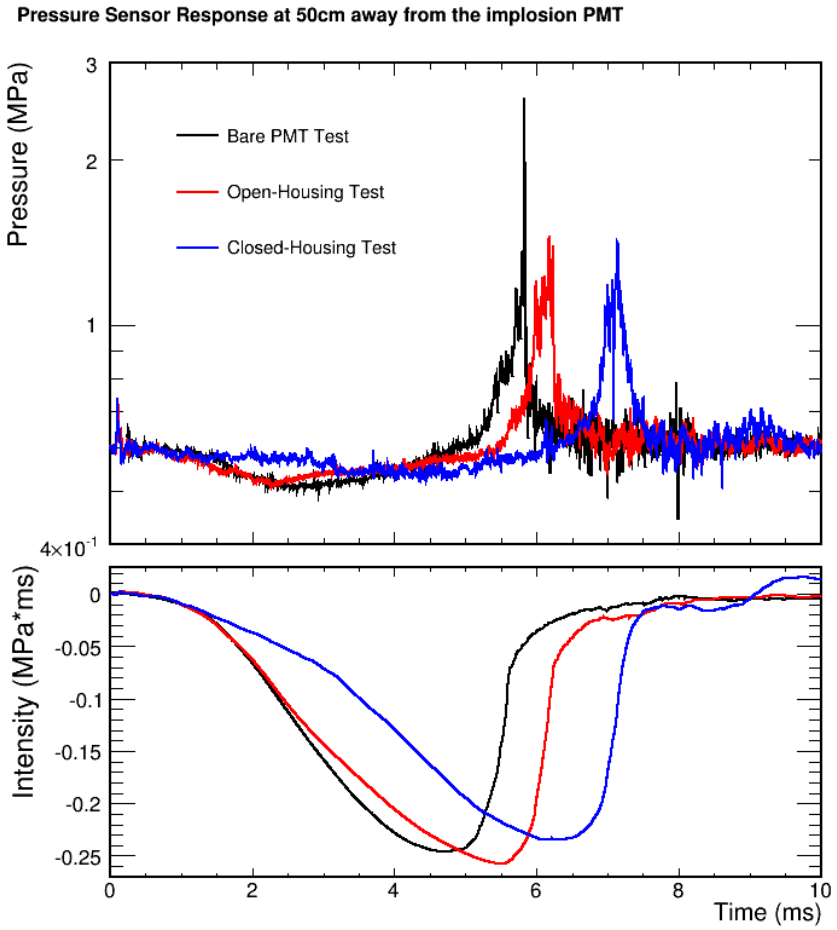


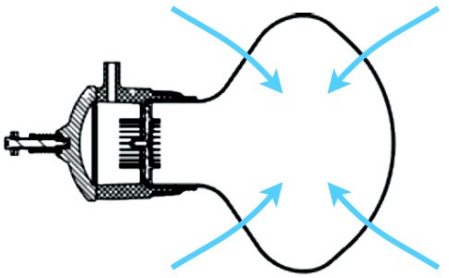


Maximal shock wave pulse intensity

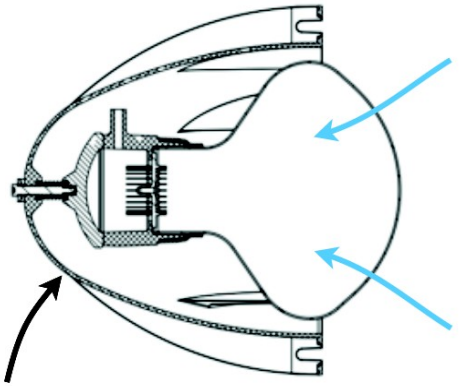
- All sensors observe the same time structure of the implosion.
- The maximal shock wave pulse intensity propagates as 1/r

Comparison of PA designs





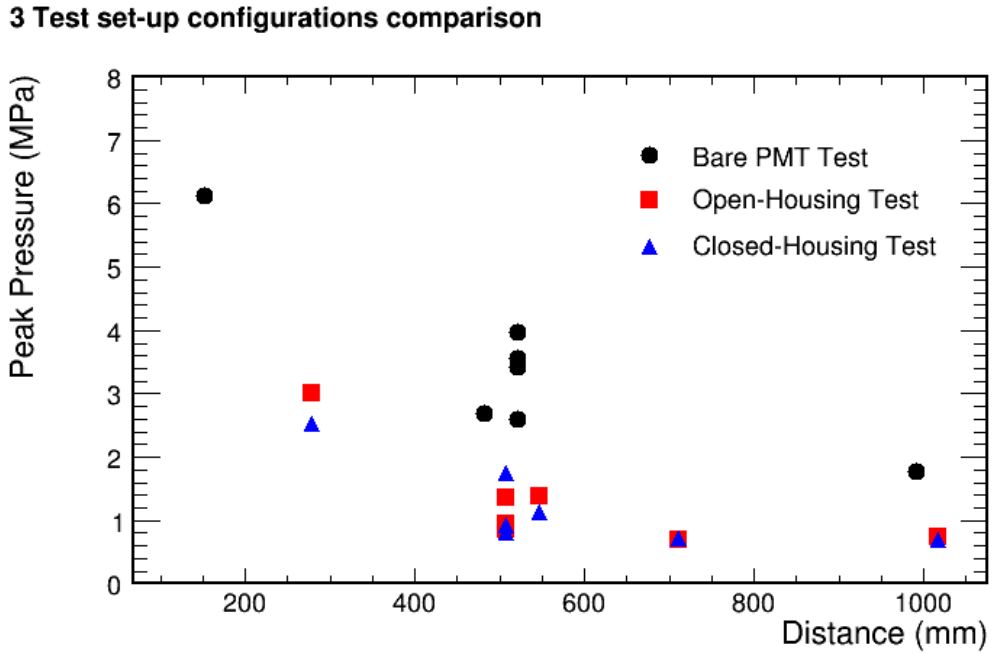
(Comparing to bare PMT)

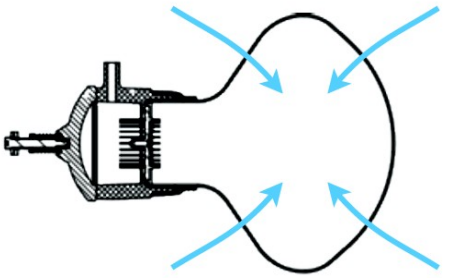


Bucket shape & ribs designed to withstand temporary differential pressure

- The protective housing and acrylic dome elongate the implosion process.
- Protective housing can reduce the shock wave peak amplitudes by ~50%.
- The total intensities of the shock wave are consistent in all cases (energy conservation).

Comparison of PA designs





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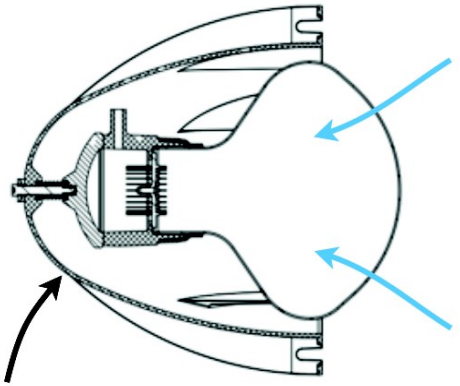

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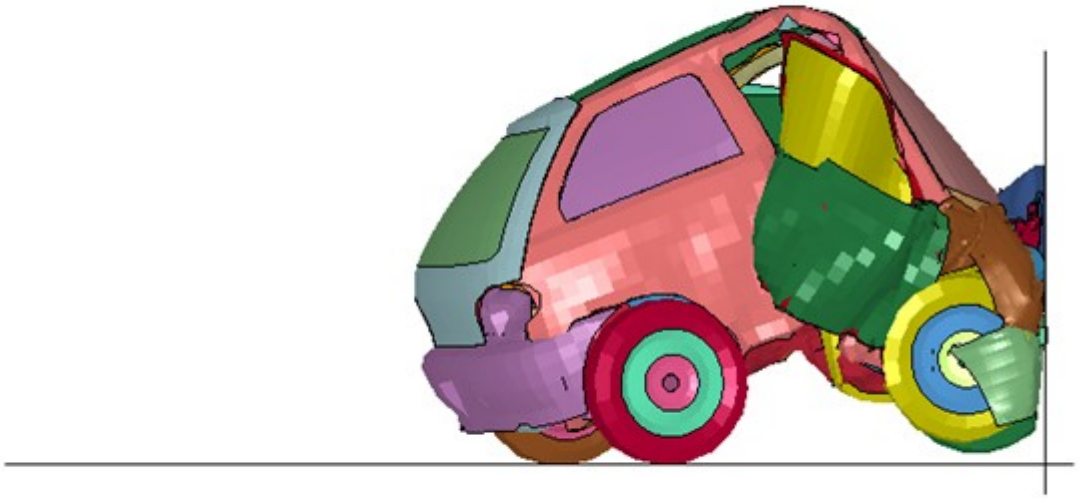
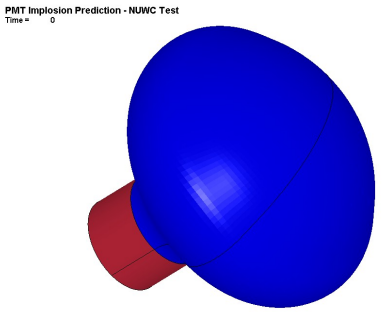
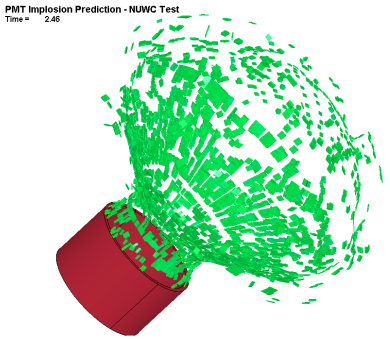
PMT Implosion Simulation

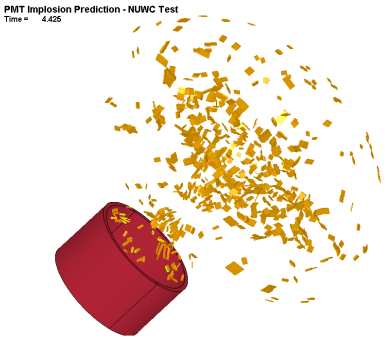


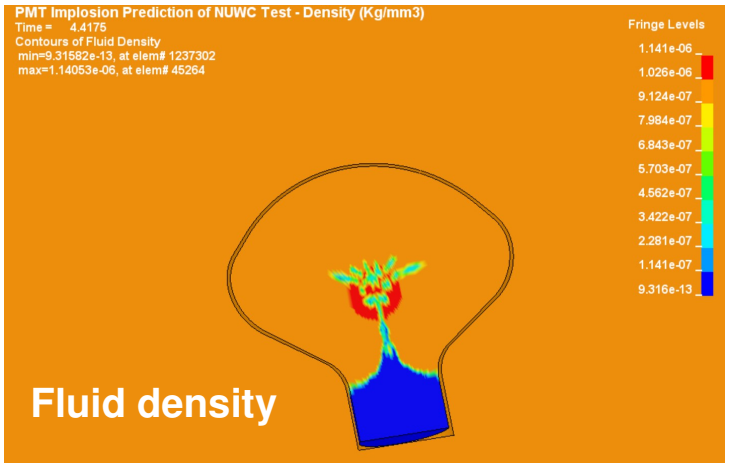
Simulation

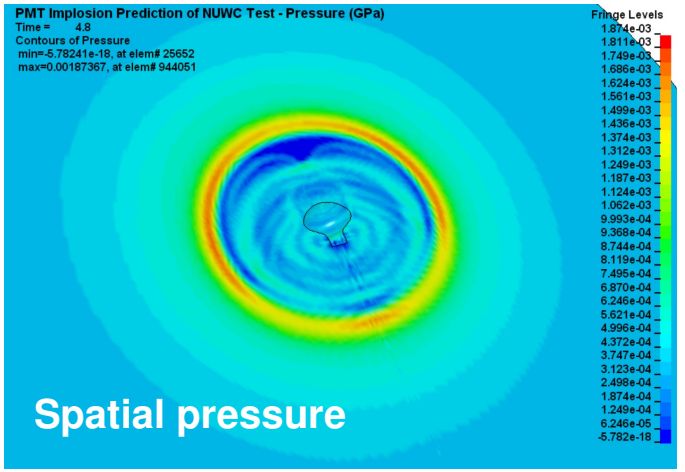
- LS-DYNA (general purpose transient dynamic finite element program)
- Arbitrary Eulerian-Lagrangian (ALE) formulation that allows PMT glass and fluid to interface.
- Based on a 2M+ fluid/solid element model and “adjusted” PMT glass constitutive and fracture relations, the implosion at 0.6 MPa water pressure are simulated (~240 hrs)



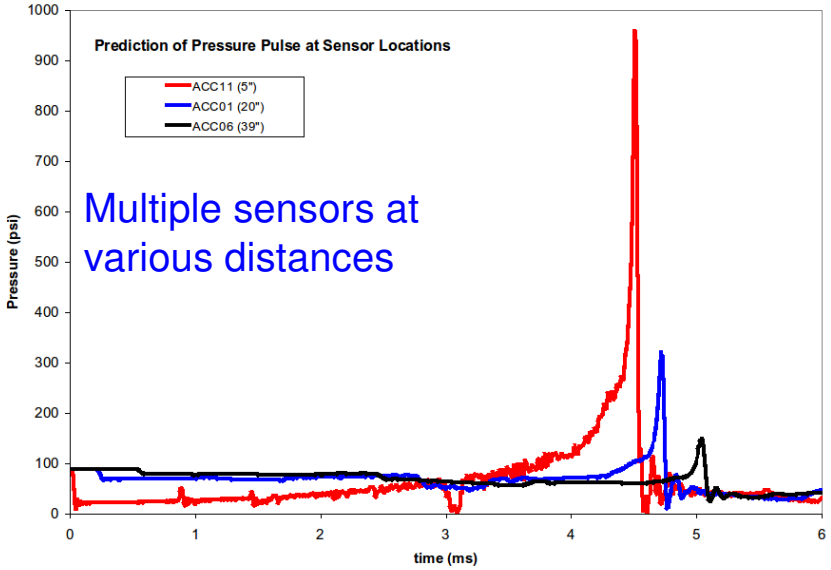








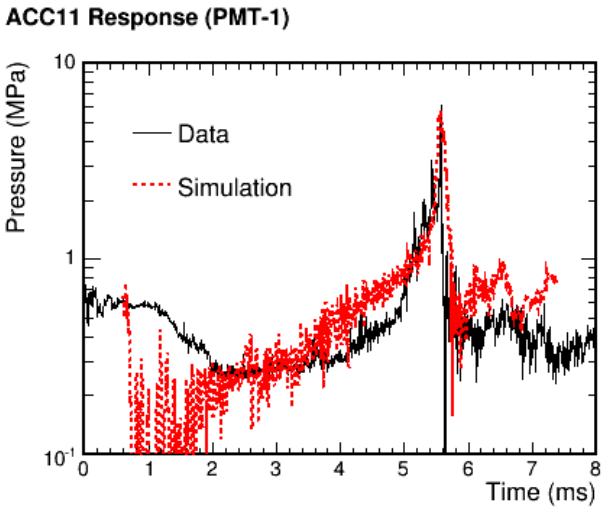
Comparison

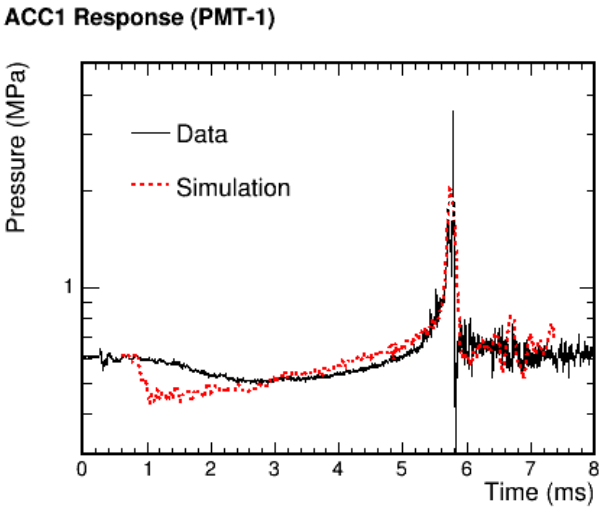


Multiple sensors at various distances

Prediction of pressure pulse at various sensor locations are close to the test results.

Confirm the attenuation (as a function of 1/r) and pulse propagation velocity (~1500m/sec).





Summary

- Successfully set up the test stand for the slow rise pressure system at BNL and underwater implosion tests at NUWC.
- 12” Hamamatsu R11780 PMT has a better mechanical performance, should has rating of 2MPa (20bar).
- PMT implosion pressure is linear with the logarithm of rate of hydrostatic pressure rise.
- No PMT cascade implosions were found with the current protective housing design for the Hamamatsu R7081 10” PMT under 0.6 MPa hydrostatic pressure.
- The PMT protective housing can effectively reduce the shock wave amplitude.
- PMT dynamic implosion are reasonably well simulated.

Acknowledgement

It has been quite a long time and huge efforts / contributions from many laboratories and universities.

- Brookhaven National Laboratory (BNL)
- Navy Undersea Warfare Center (NUWC)
- Physical Science Laboratory (PSL) at Wisconsin University
- Fermi National Accelerator Laboratory (FNAL)
- Multi-functional Material Laboratory (M&M-Lab) at Alfred University