PMT Production Rates, Strength, and Glass

R. Svoboda, April 12, 2018

PMT Glass: A major background

What type of glass is available?

12” HQE Hamamatsu PMTs

Standard Glass

U: 0.341 ppm
Th: 1.33 ppm
K: 0.026 pct

Low radioactivity (LRI) glass

U: 0.043 ppm
Th: 0.134 ppm
K: 36 ppm

11” ADIT/ETL (Texas) PMTs design goals

U: 0.030 ppm
Th: 0.030 ppm
K: 60ppm

Quick Rule of Thumb

For WATCHMAN, going from STD to LRI glass is about the same as adding an addition ½ meter of buffer

(work of Marc Bergevin)

LRI glass 10-in PMTs cost about 15% more than STD glass PMTs. The QE and performance are expected to be identical.

REGULAR GLASS	LOW BACKGROUND GLASS
• Delivery time about 36 months • Full mechanical strength testing done - don’t need to do anything more • Available in 12-inch • Require larger tank for same fiducial volume	• Delivery time about 36 months • costs 15% more per PMT • Untested mechanical strength - would need to do this • No 12-inch option • Smaller tank and excavation

WbLS PMT Potting

Informal MOU between Hamamatsu, BNL, UC Davis, LLNL to develop WbLS potting

Current status is that all components of Hamamatsu potting seems OK in WbLS except for one sealant. A replacement for that sealant is currently being actively tested.

PMT Implosion Chain Reactions

Even with good quality control, microscopic cracks in the PMT glass act as concentrators of stress. Once the concentrated stress exceeds the strength of glass, it will lead to cracking and failure (implosion). As the PMT glass shatters and water rushes inwards, filling the vacuum inside the PMT glass enclosure, a shock wave may form by the collision of the in-rushing water, which then propagates outward [11,12]. The resulting shock wave can potentially impact neighboring PMTs with enough force to cause them to fail, leading to a cascade failure.

The Issues

- In 2001 a chain reaction of implosions triggered by a single PMT failure destroyed 7,877 PMTs (6,777 20-inch and 1,100 8-inch) in the Super-Kamiokande detector in Japan.
- Super-K did a series of studies for their 20-inch PMTs on muffling the explosions with FRP covers with UVT acrylic faceplates
- LBNE also did a series of studies (summarized here)
- Low radioactivity glass has not been studies for implosion chain reaction resistance - how serious is this potential problem?

Contents lists available at SciVerse ScienceDirect

Nuclear Instruments and Methods in Physics Research A

journal homepage: www.elsevier.com/locate/nima

Underwater implosions of large format photo-multiplier tubes

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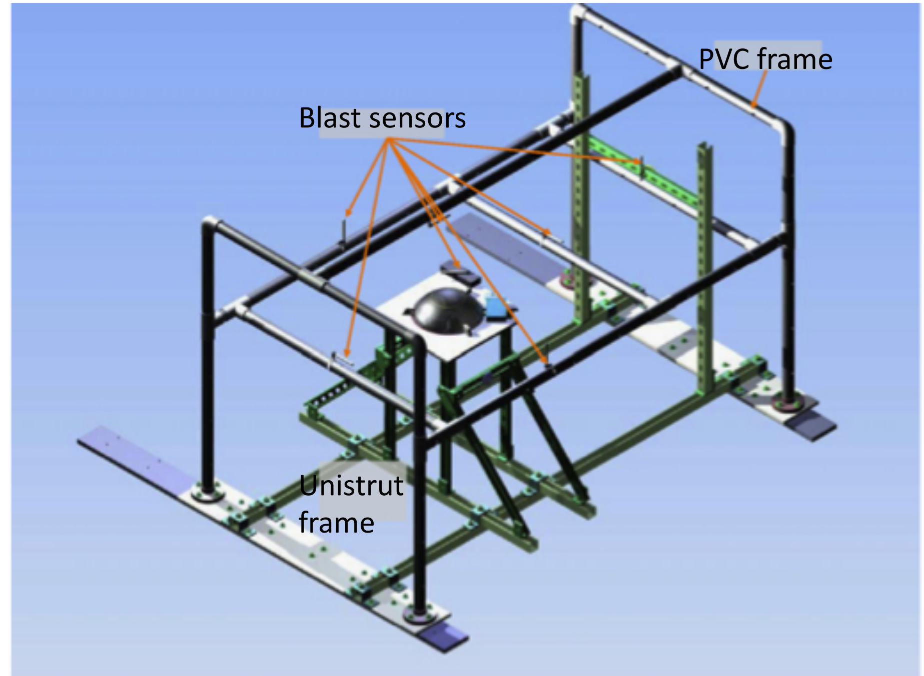
Detailed study of hydrostatic implosion mechanism for Hamamatsu 10-inch PMTs made with standard glass



Propulsion Noise Test System (PNTS) at NUWC in Newport, R.I.

15 meters in diameter, nearly two kilotons of water. Can be pressurized up to 0.69 MPa (about 6.9 bars). WATCHMAN will be about 2 bars.

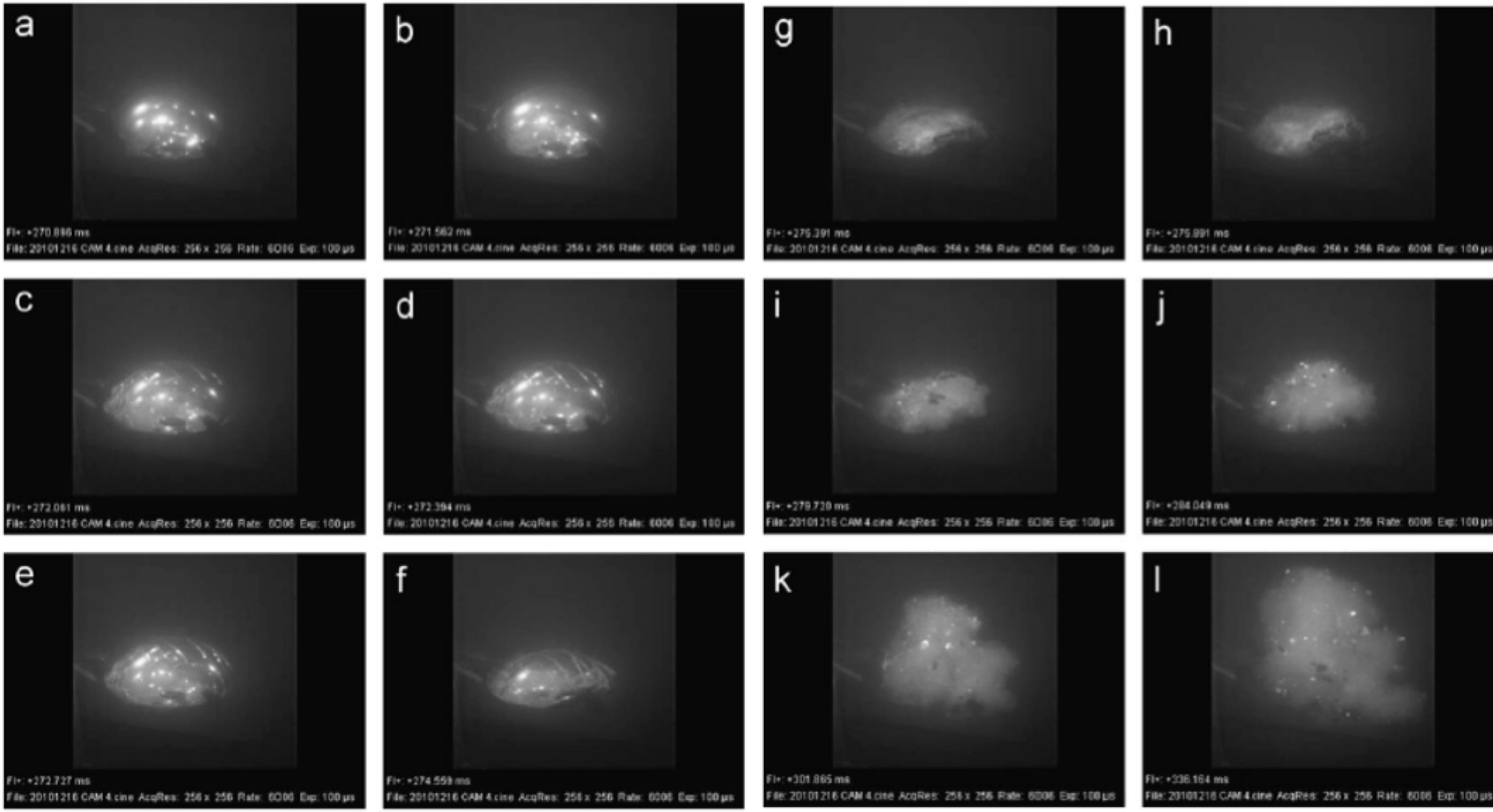
Fast cameras and blast sensors used to characterize implosion

PMT installed in holder that is attached To PMT equator

Far from wall, but also offset from center

Pneumatic plunger used to break PMT

Pressure at PMT 6.1 bars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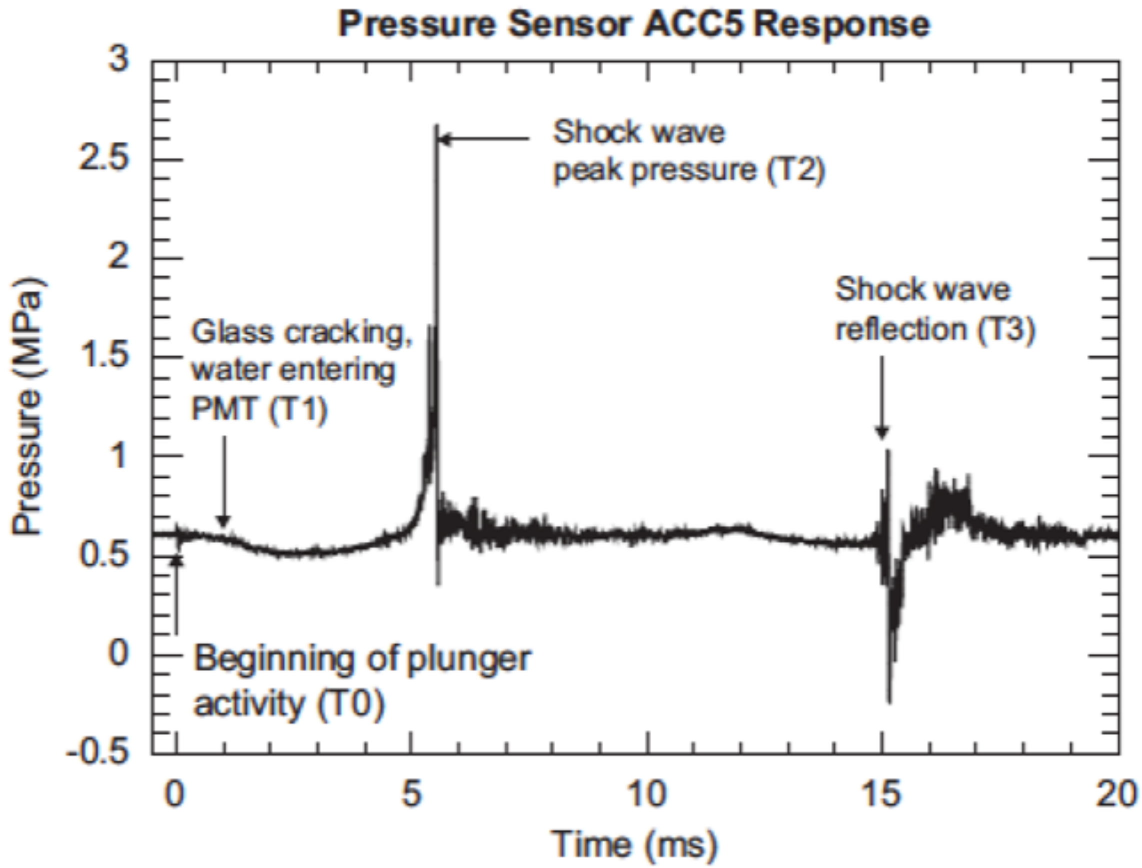


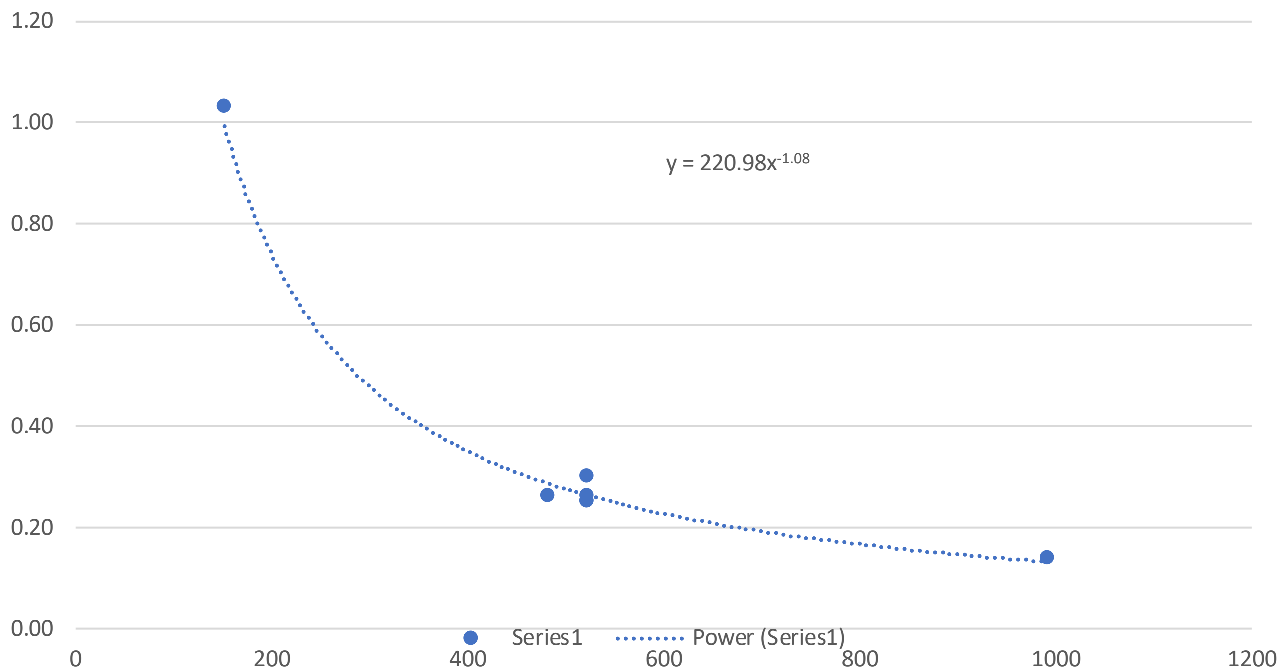
Fig. 6. The pressure waveform data of the PMT-1 implosion recorded by blast sensor ACC5.

Good agreement of blast intensity with "bubble" model, which predicts 1/r

Table 1
Responses of blast sensors in PMT-1 implosion test.

Sensor	Dist (mm)	T0 (ms)	T2 (ms)	T2–T0 (ms)	P_{peak} (MPa)	I (MPa ms)
ACC11	152	0.000	5.570	5.570	6.13	1.03
ACC5	482	0.260	5.800	5.540	2.68	0.26
ACC1	521	0.260	5.785	5.525	3.55	0.26
ACC2	521	0.245	5.780	5.540	3.97	0.30
ACC3	521	0.235	5.830	5.595	2.59	0.25
ACC4	521	0.245	5.825	5.580	3.43	0.25
ACC6	991	0.560	6.150	5.590	1.77	0.14

Lots of variation in peak intensity indicates implosion not Isotropic in peak

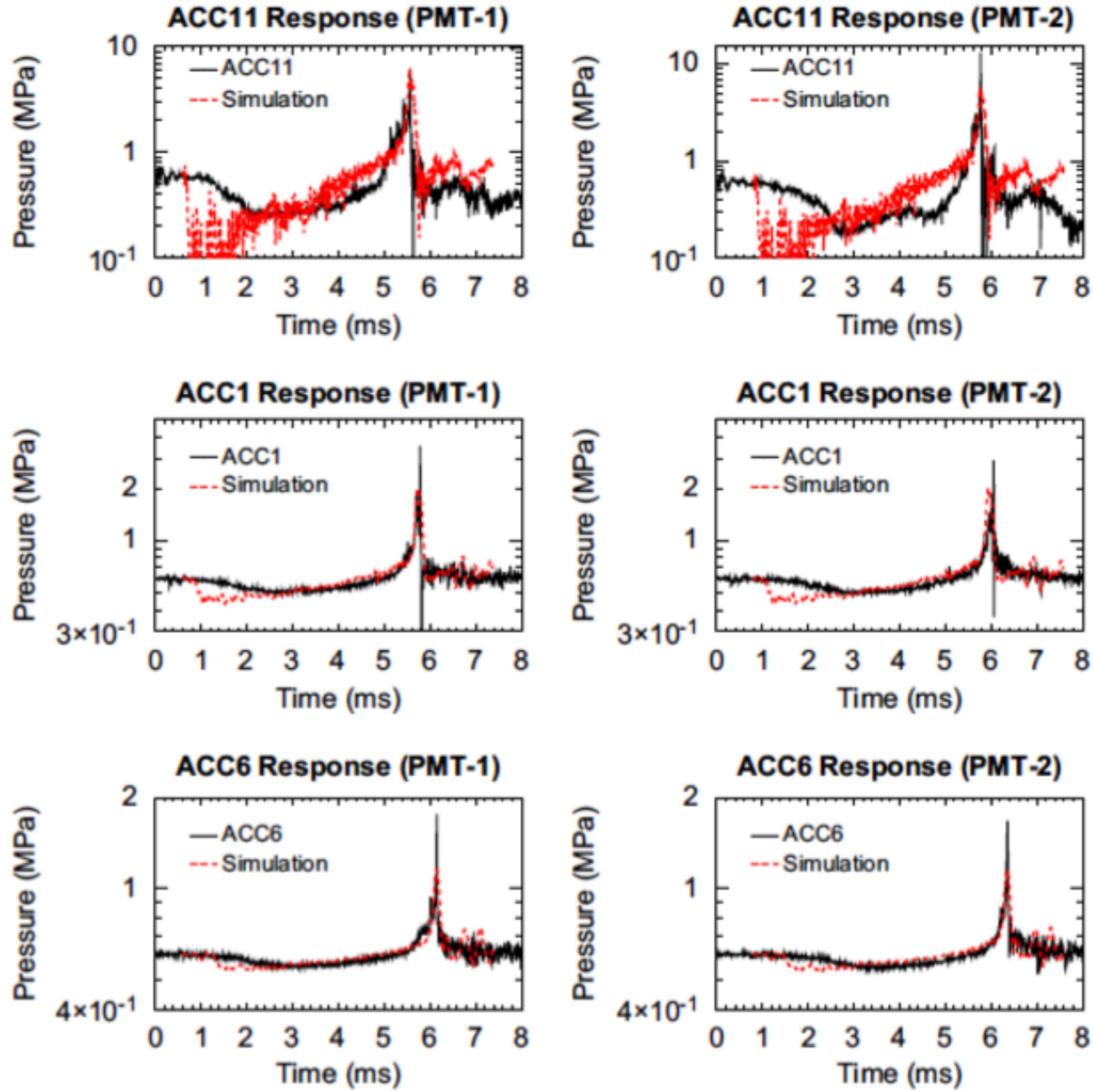


Code developed to model implosion results

Near wall

1.0 m

0.5 m



LS-DYNA from LSTC Software, Livermore, California

(Does LLNL have expertise and license?)

Conclusion: Good implosion model but not breaking model

From this paper

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Implosion chain reaction mitigation in underwater assemblies of photomultiplier tubes

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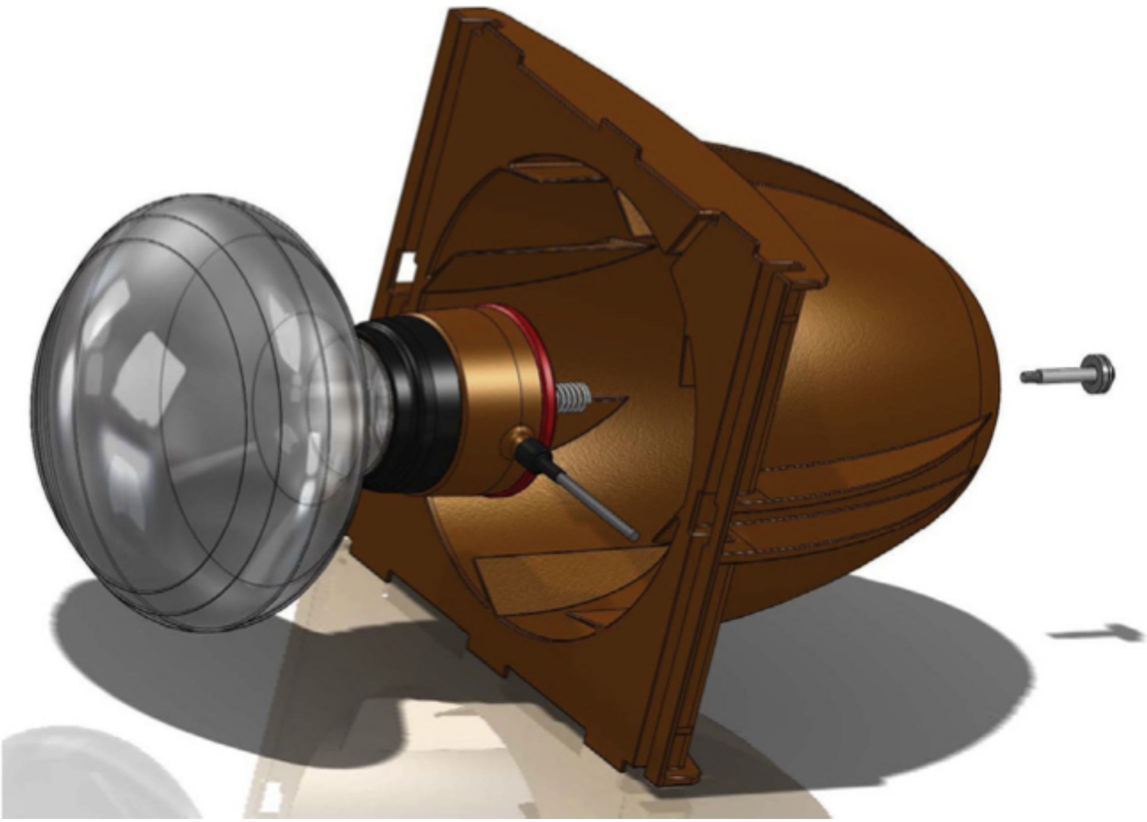
Study of Implosion Chain Reactions. Used 10-cm standard glass PMTs mounted in plastic cones with a spacing of 50 cm

LBNE PMT Holder Design from BNL



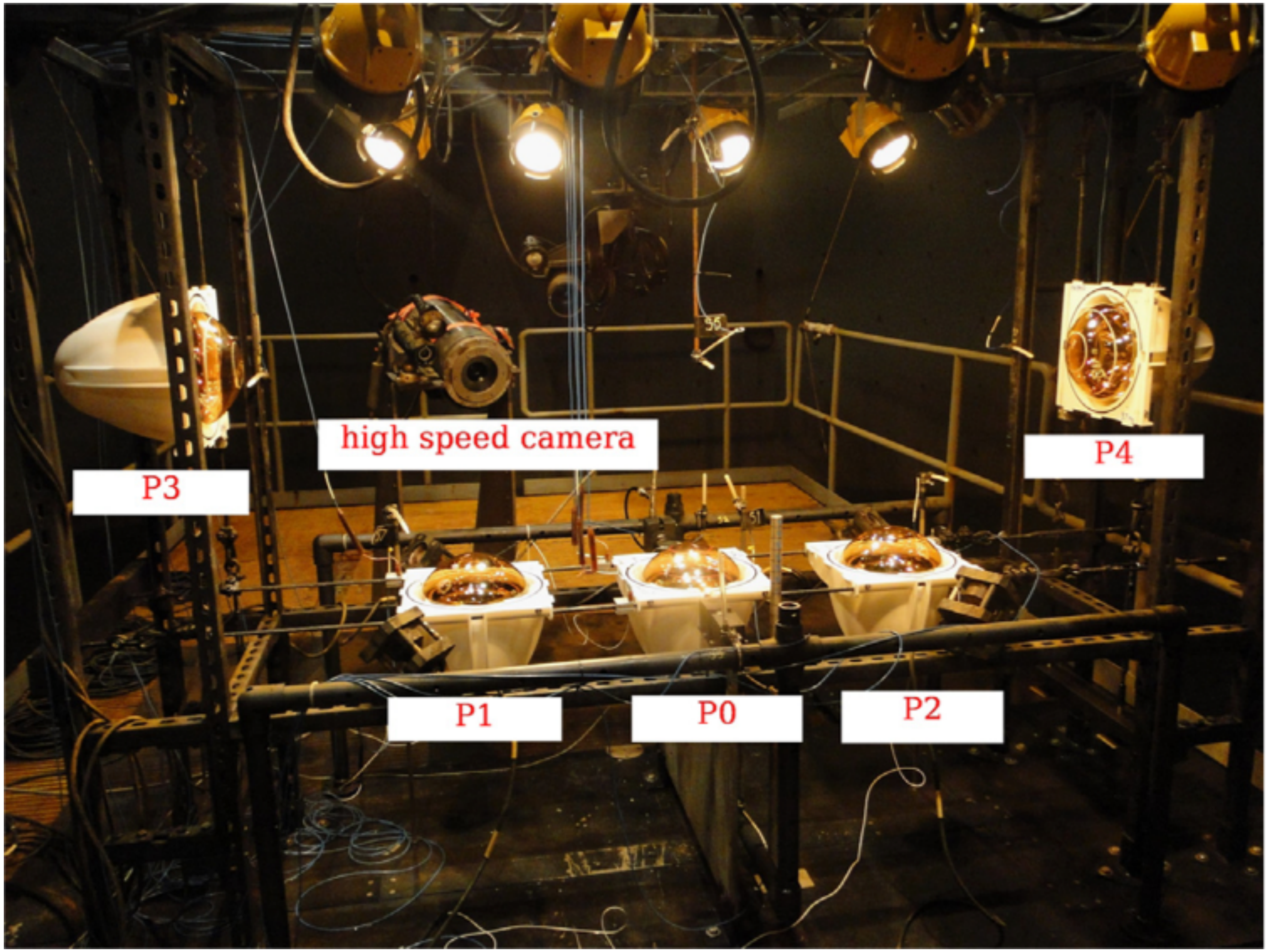
Injection molded ABS (may not be long-term compatible) 4 mm thickness

Designed for 10-inch Hamamatsu

These tests done with urethane instead of ABS

Note: this paper has a good description of the holder mechanism

NUWC Test Tank Setup



PMT P0 is intentionally broken to see if a chain reaction occurs

Three separate tests performed, with all PMTs changed out between tests

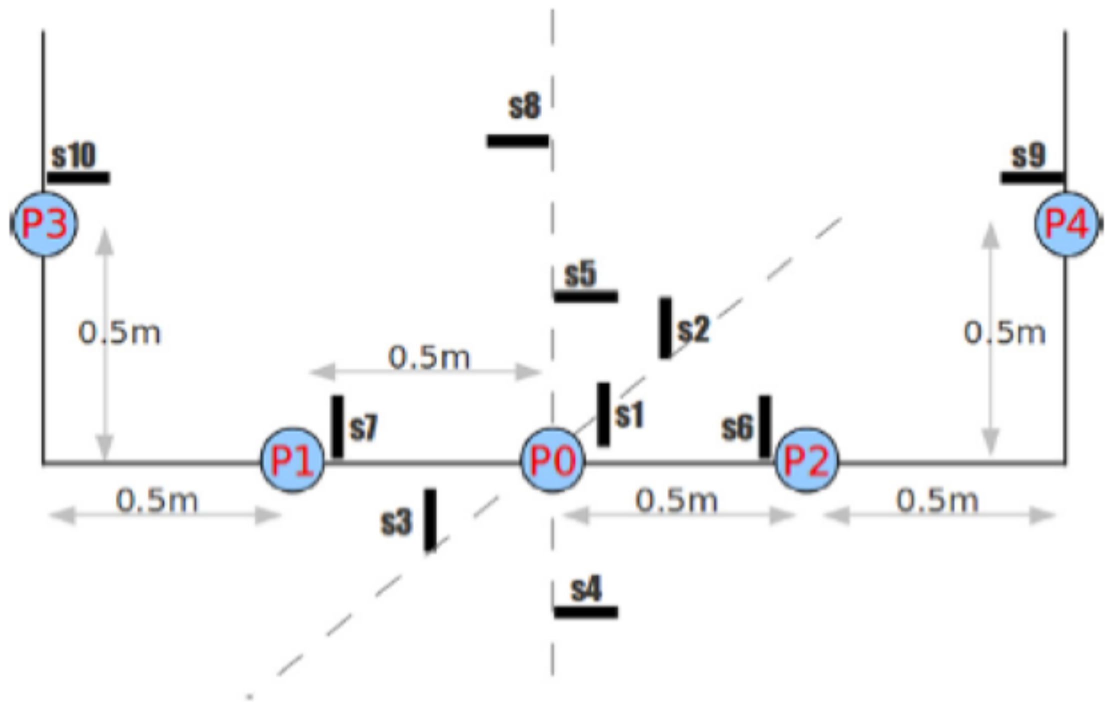
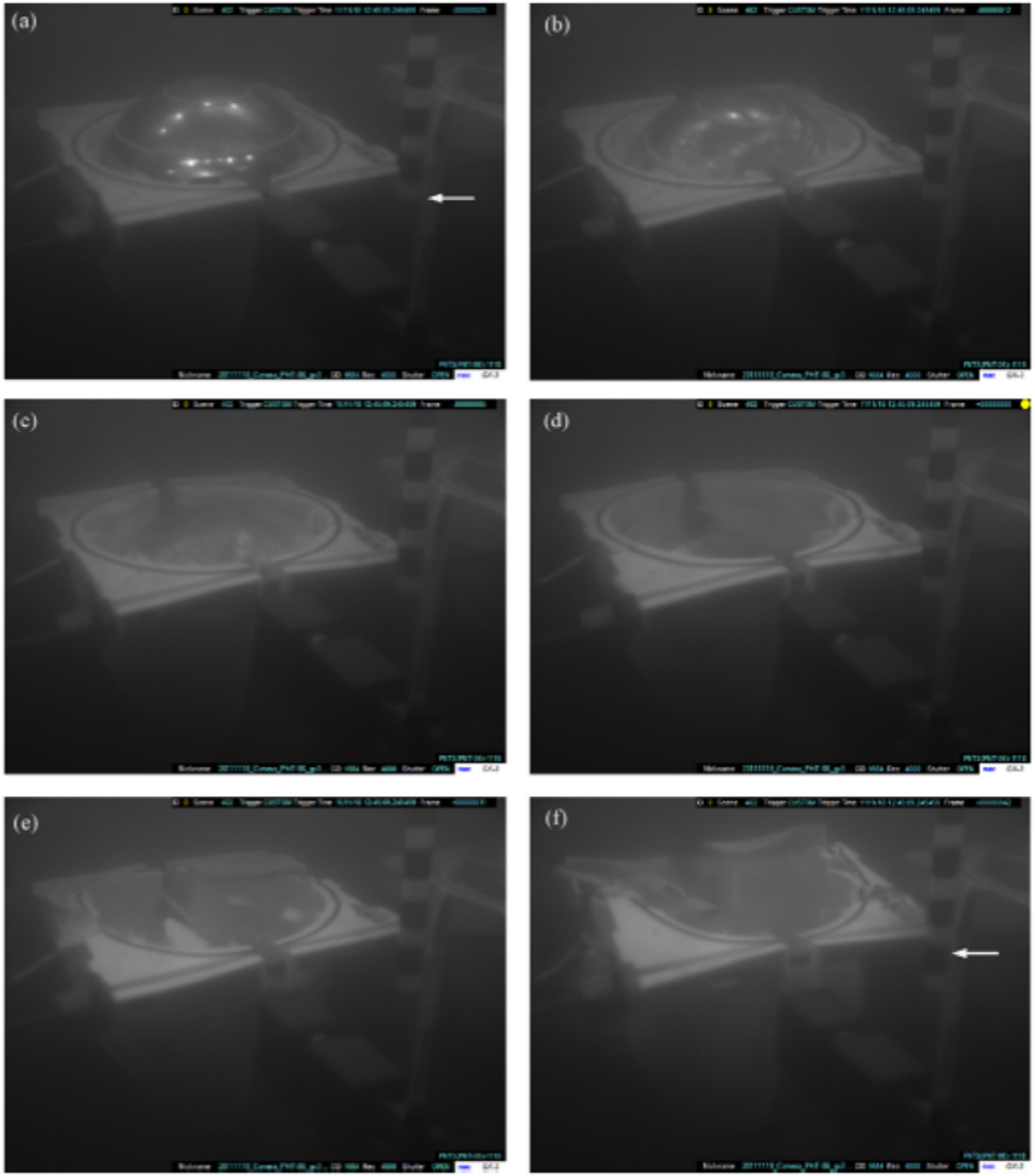


Fig. 3. The schematic drawing of the locations of the PMTs and PCB ICP blast sensors (not to scale). The imploding PMT is mounted at P0.

Table 1
The distance of blast sensors to the center of the imploding PMT.

Sensor	S1	S2	S3	S4	S5	S6	S7	S8	S9	S10
Distance (mm)	279	546	508	508	508	711	711	1016	1143	1143


(a)
(b)
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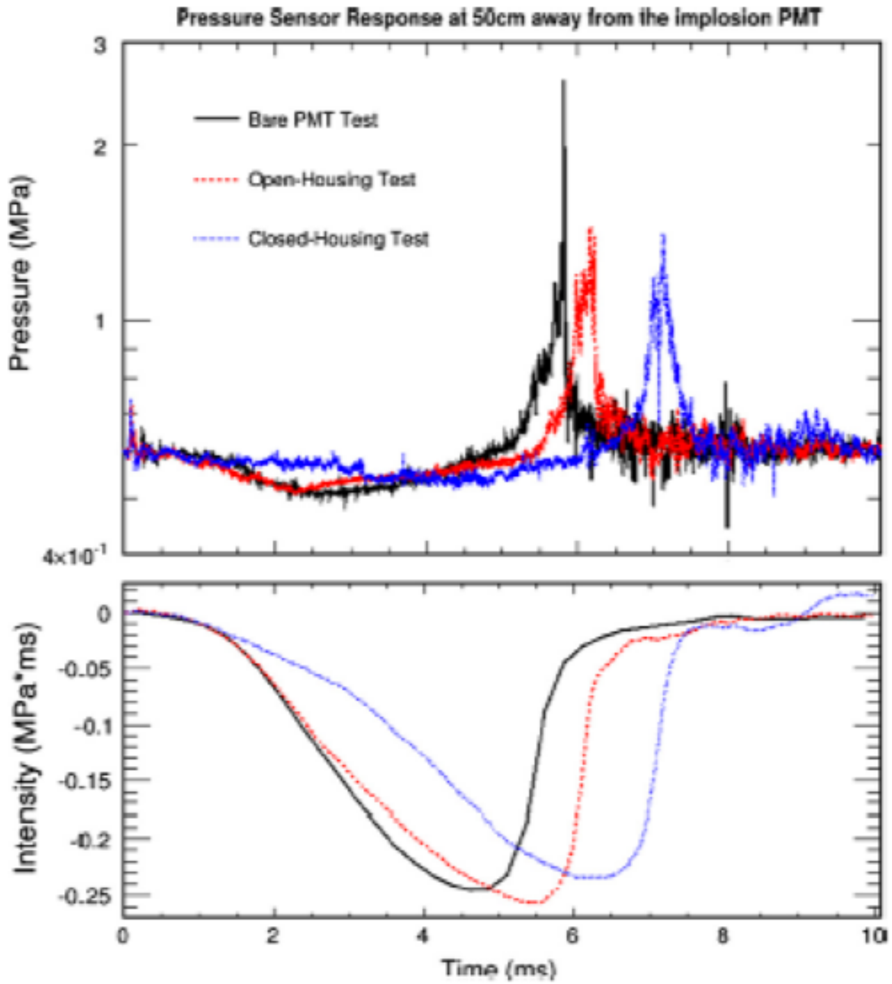


Fig. 8. The pressure waves and intensities of three different PMT implosion setup configurations recorded by the blast sensor 50 cm away from the PMT. No averaging of the data was performed for this plot, so that the sharp rise of the shock wave can be seen.

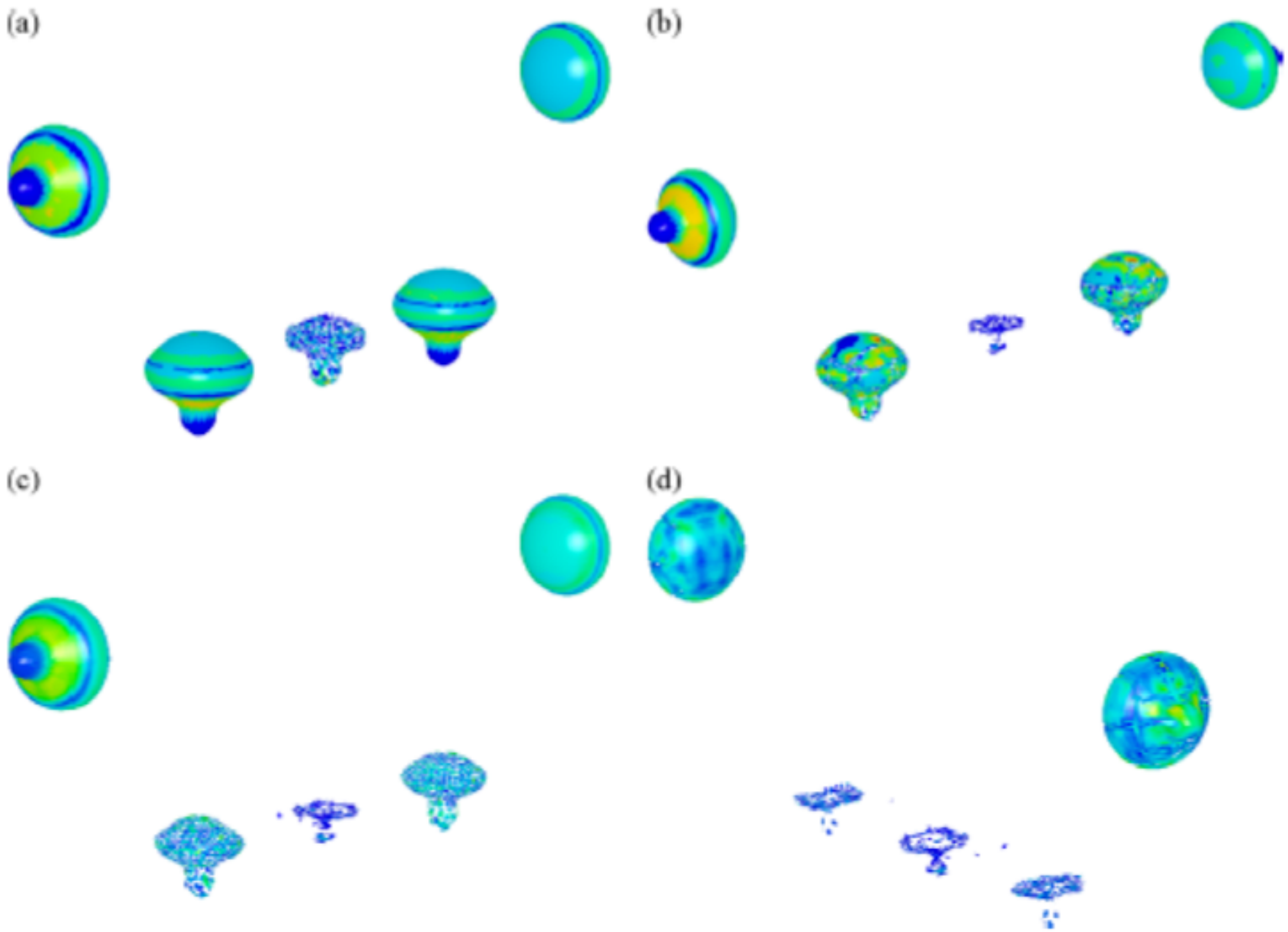
Bare PMT versus

Open-Housing versus

Closed-Housing (i.e. a UVT acrylic cover)

The pulse is spread out and reduced in peak intensity

Simulated chain reaction of 10-inch bare PMTs



Implied Scaling

Based on empirical fitting of the numerical calculation results of the differential equations provided by Keller and Kolodner [20] with different initial conditions, we can get an estimation of the relationship of the shock wave pressure with the PMT volume and water pressure, assuming that the implosion is spherical and the water static pressure is not affected by the implosion,

$$P_{peak} \propto \frac{P_{static}^{1/2} \times V_{tube}^{1/3}}{r} \quad (1)$$

where P_{peak} is the peak shock wave pressure, P_{static} is the static water pressure, V_{tube} is the volume of the PMT, r is the distance from the center of the PMT, and r is large enough to be always in the water phase. Based on this empirical formula, we can easily estimate the scale of peak pressure of the shock wave for any PMT

This test was done at 7 bars, whereas in Theia our depth may be
depth is 2-3 bars. This reduces the peak shock by a factor of 1.5 or so, but
we don't know the importance of the glass strength in determining
If this is too high still

Conclusions

- Low background glass is available and will reduce backgrounds compared to SK and SNO+. This reduces the needed detector size and the number of PMTs needed.
- This glass is known to be weaker, however, and some testing may need to be done for Theia.
- Delivery times seem to be equivalent, but there is a cost increment of about 15%
- Development of a WbLS compatible potting is underway and making progress