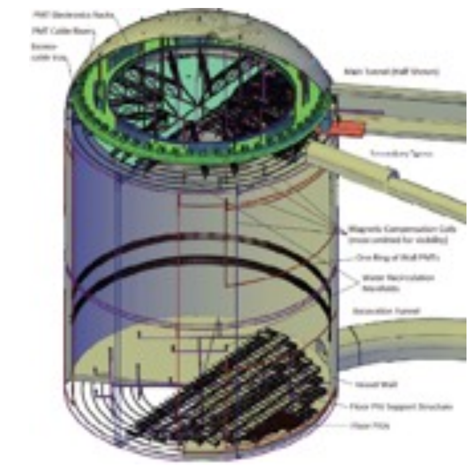
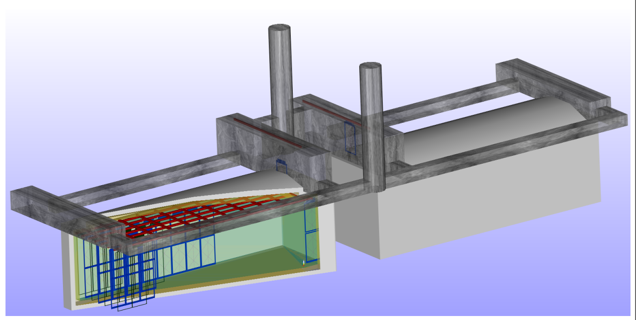


Mechanical issues concerning Photo-multipliers for LBNE

Milind Diwan
ANT 2011, Dexel University,

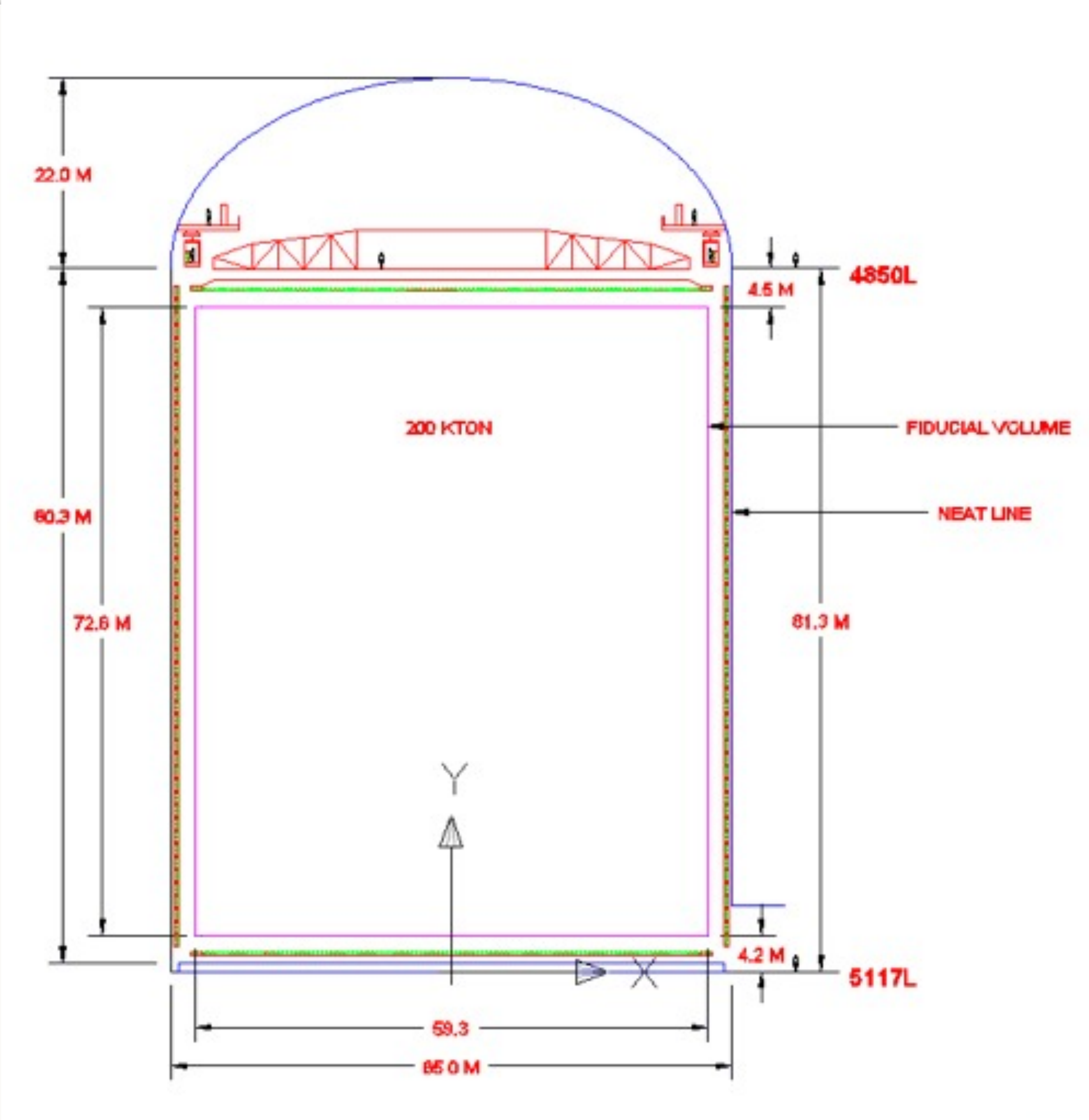
Could be useful for other experiments also !



BROOKHAVEN NATIONAL LABORATORY

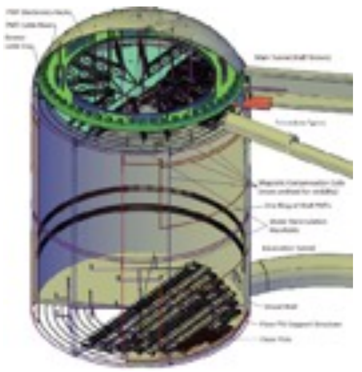
THE ENVIRONMENT

- Ultrapure water, 18MOhm-cm
- Temperature ~13^o C
- Hydrostatic pressure ~1.5m to ~80m of water.
- 80m = 7.8 bar = 7.7 atm = 784kPa= 113 psi
- ~30000 tubes 10-12 inch diameter



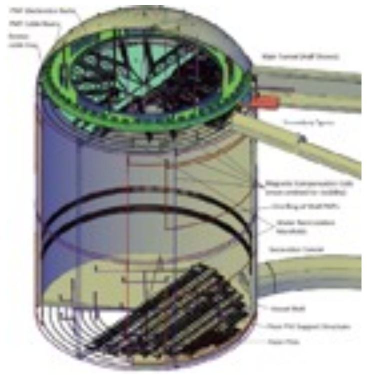
1atm =14.7 psi =10.3 m water =1 bar = 101325 pa

Review of requirements

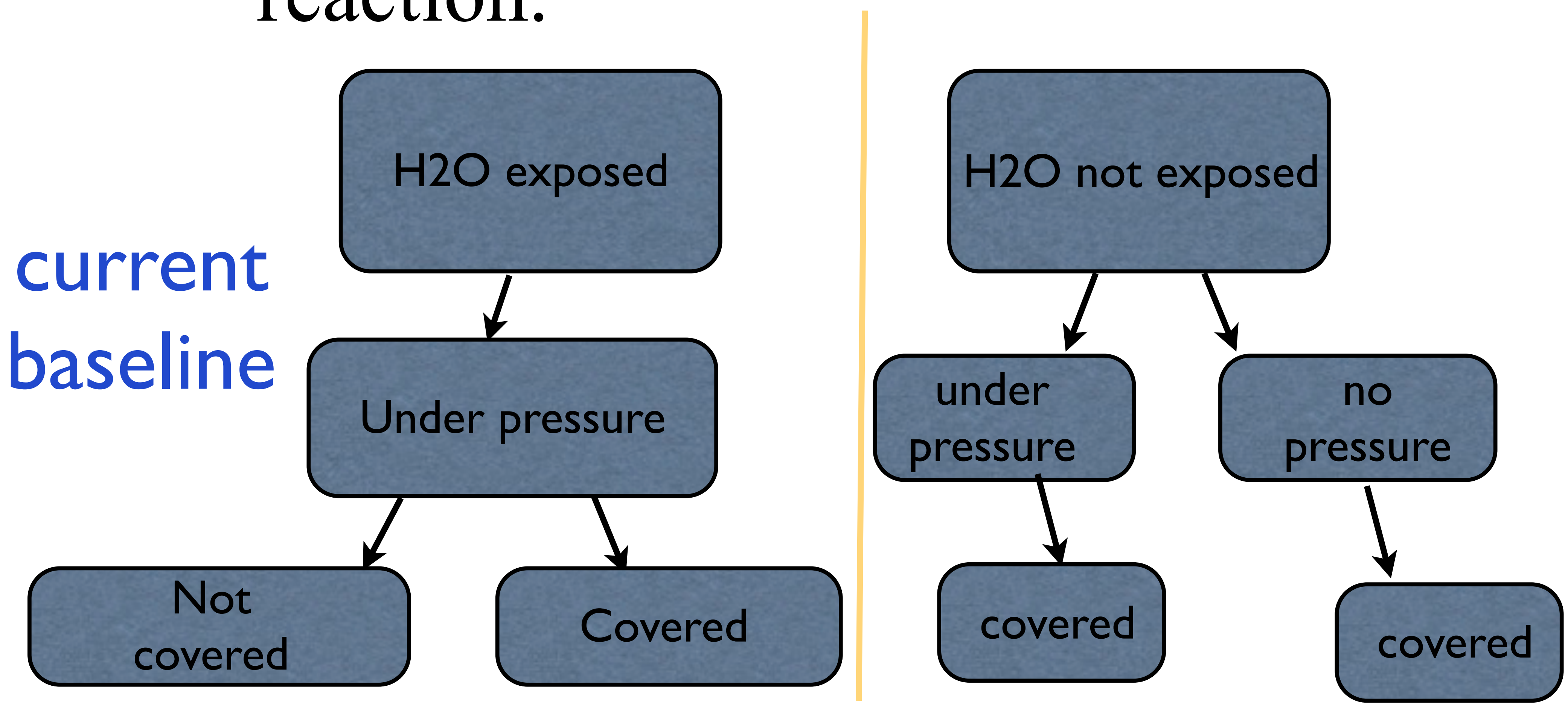


- Minimize the risk of single PMT implosions. No more than 1%/year failures for any single channel. (including PMT, base, cable, eletronics).
- We need 20 year lifetime for the PMTs. (some reviewers would like 30 yr !)
- Eliminate the risk of catastrophic chain reaction of PMT implosions.

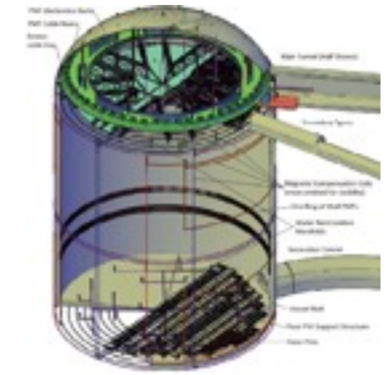
Design Choices

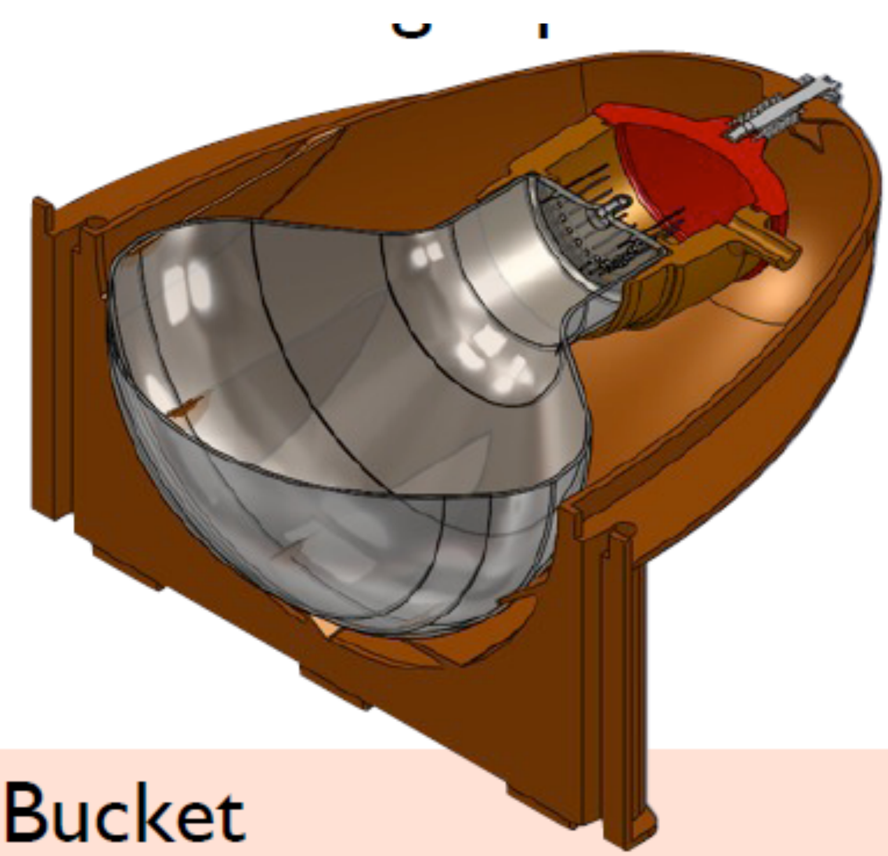


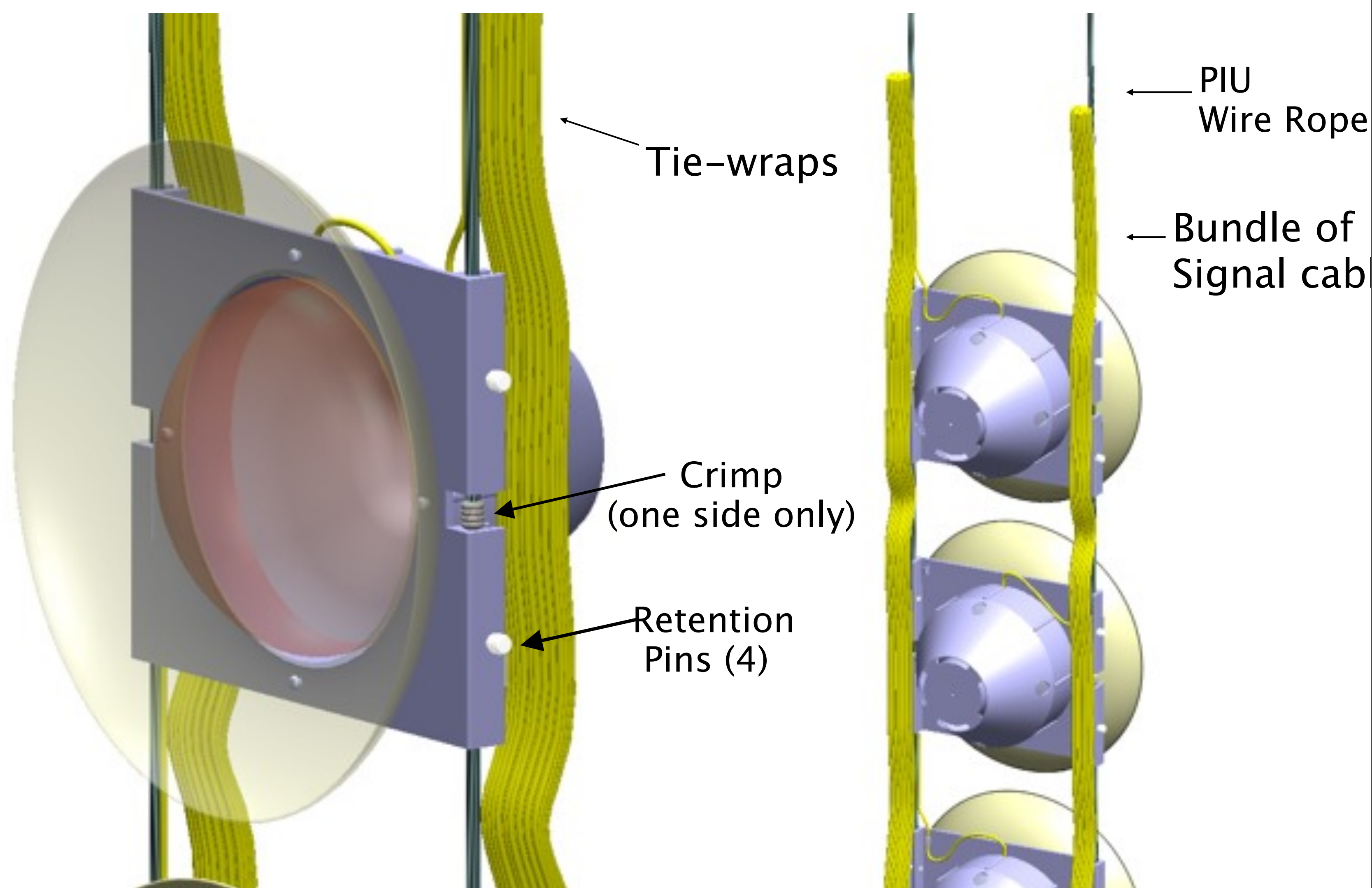
- PMT exposed/not exposed to water
- PMT exposed/not exposed to pressure
- PMT covered/not covered to mitigate chain reaction.



Current design



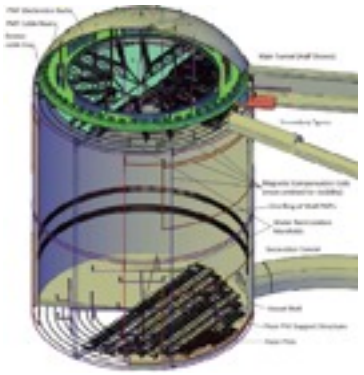




Bucket

- Shell around back side may reduce impact of PMT implosion
  - ➡ *Implosion dynamics under study by simulation and planned tests*
- Base cup protects pins area from hydrostatic pressure
- Bulb is fully exposed to hydrostatic pressure

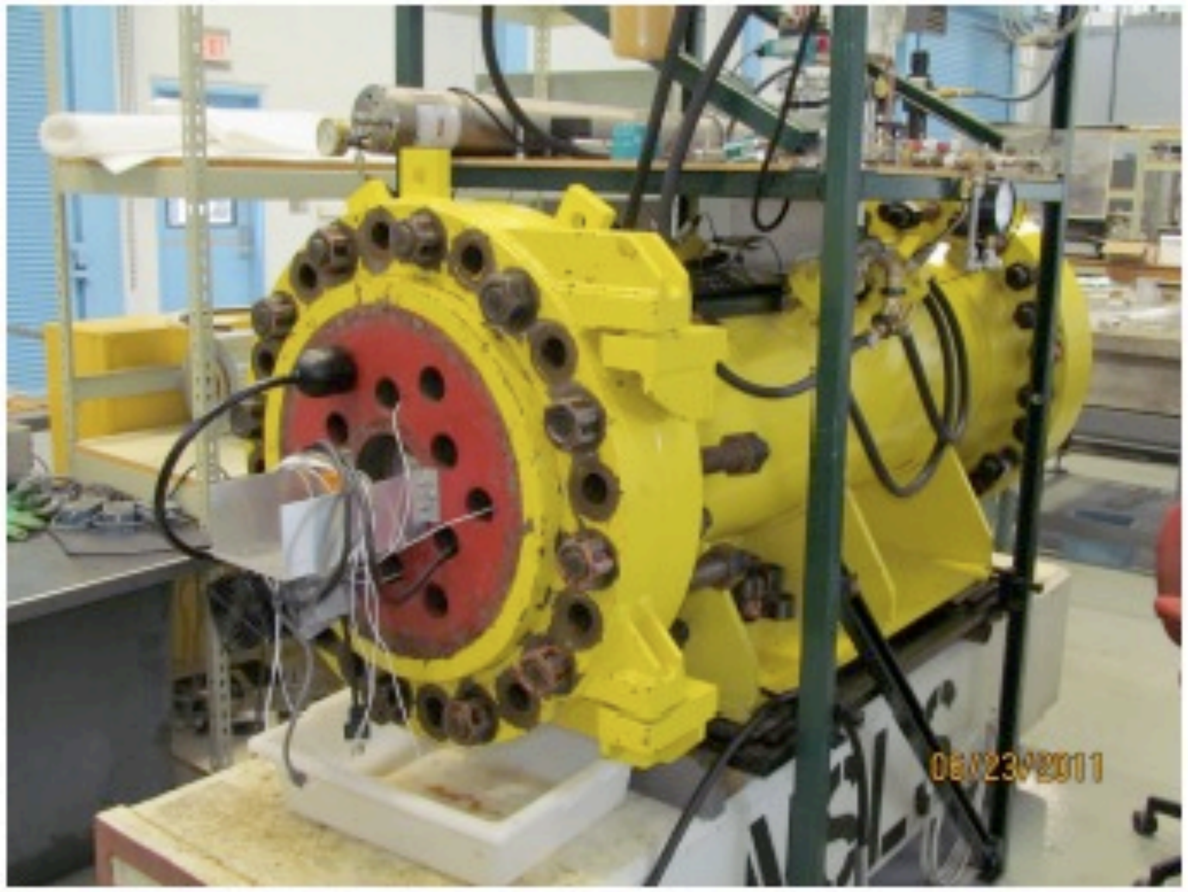
Topics

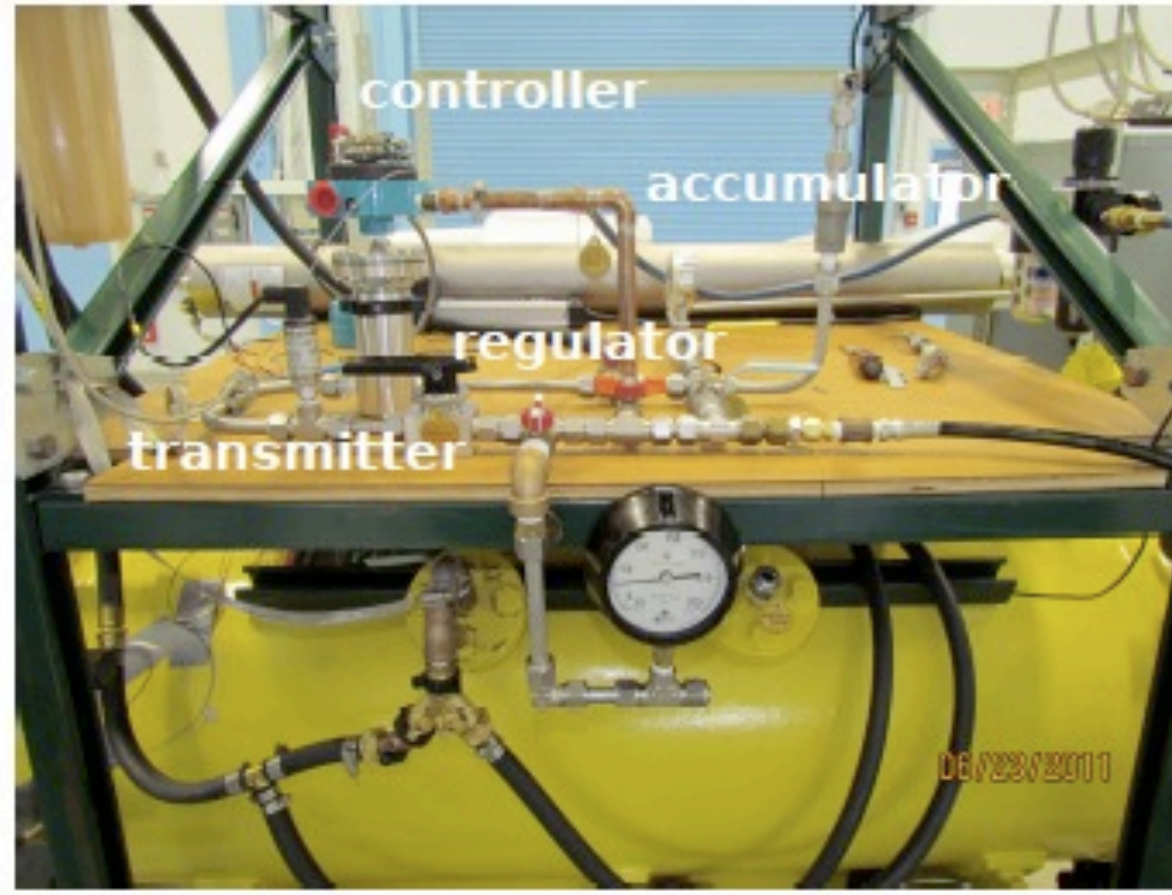


- Static pressure performance
- Glass performance over time
- Chain reaction testing and mitigation.

BNL Slow Rise system

K. Sexton



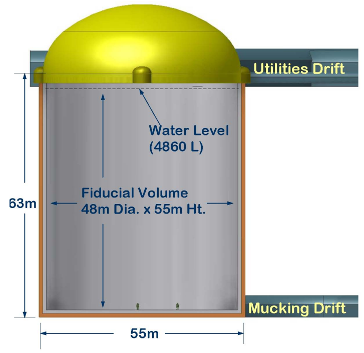


Slow rise system:

- BNL pressure vessel tank (50gal, up to 350psi)
- High pressure accumulator feed in (3gal, upto 2000 psi)
- Tap water feed in (upto 60 psi)
- Regulator / transmitter feed back
- ER3000 Electronic Pressure Controller
- Tuning the default software to stabilize the pressure in the tank
- Adding Labview code to control the pressure rising function

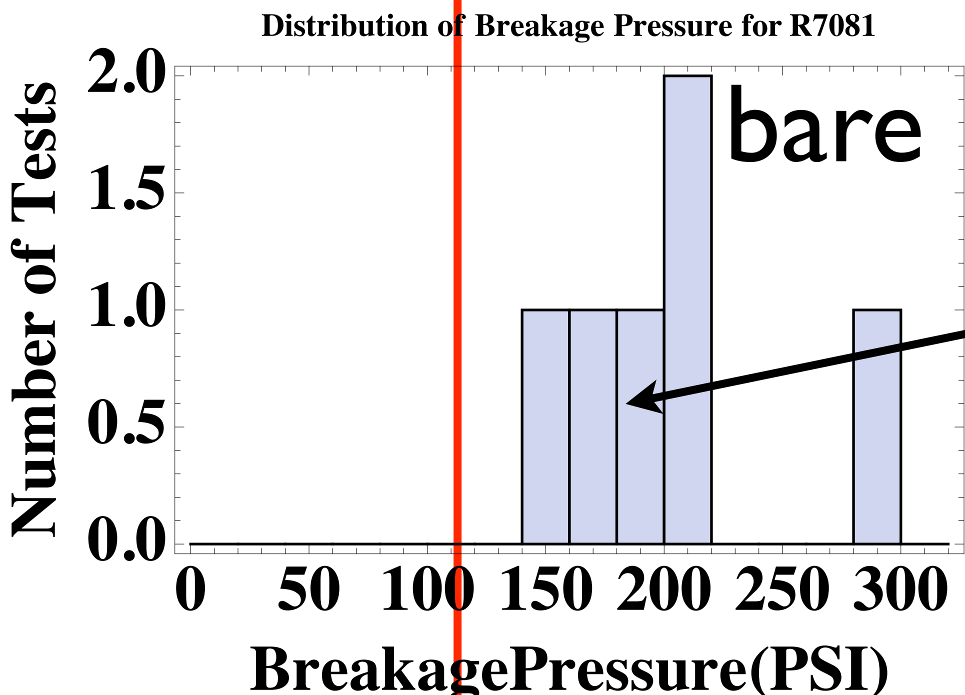
3

inside diameter: 20 inch



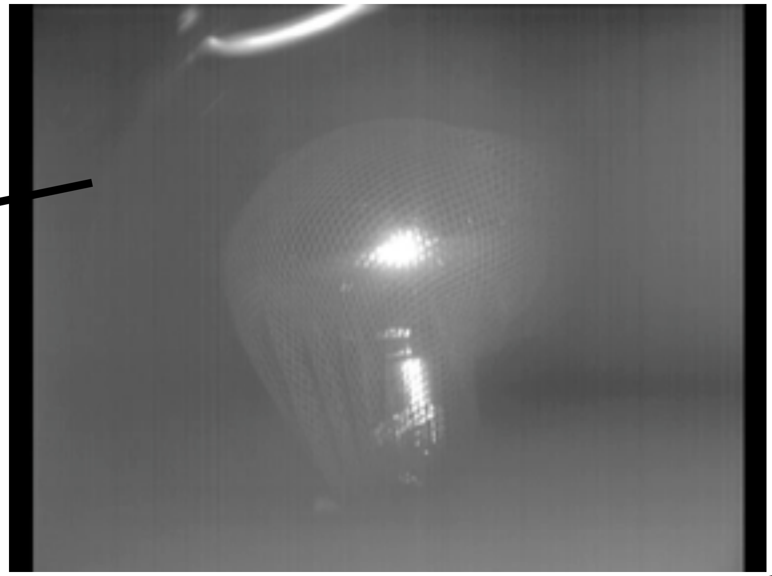
Current data-set

110psi

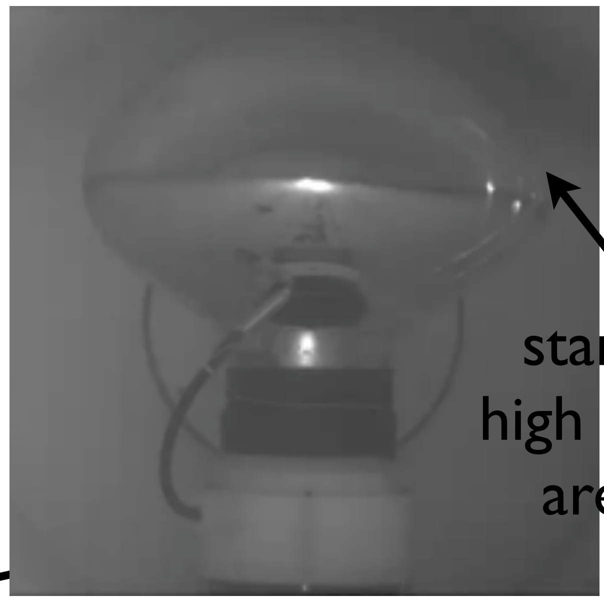


bare

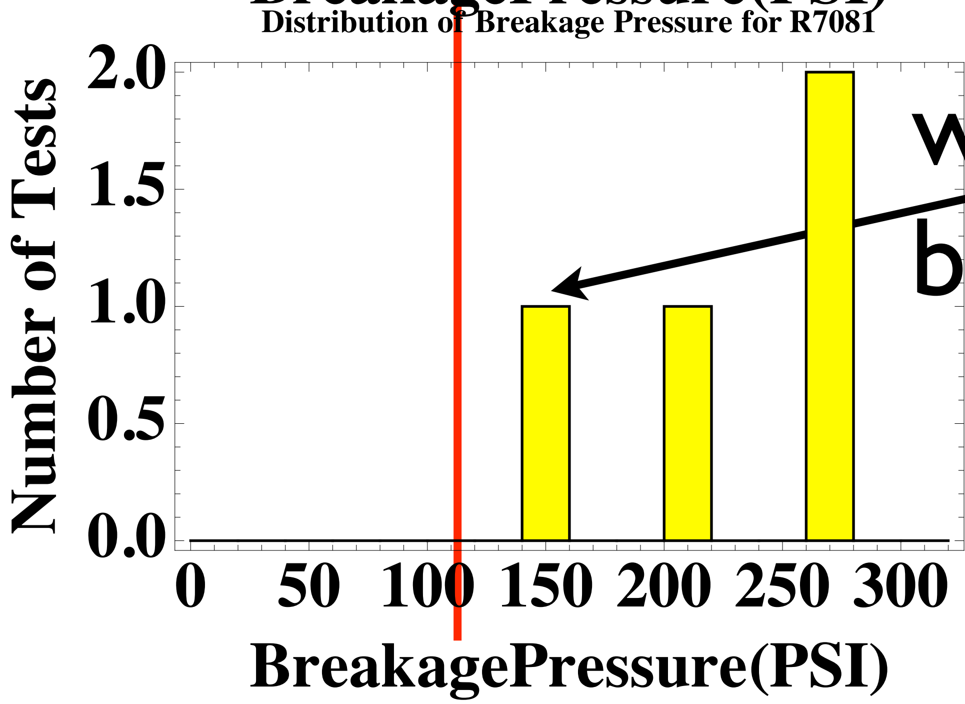
Ta 3085 194 psi



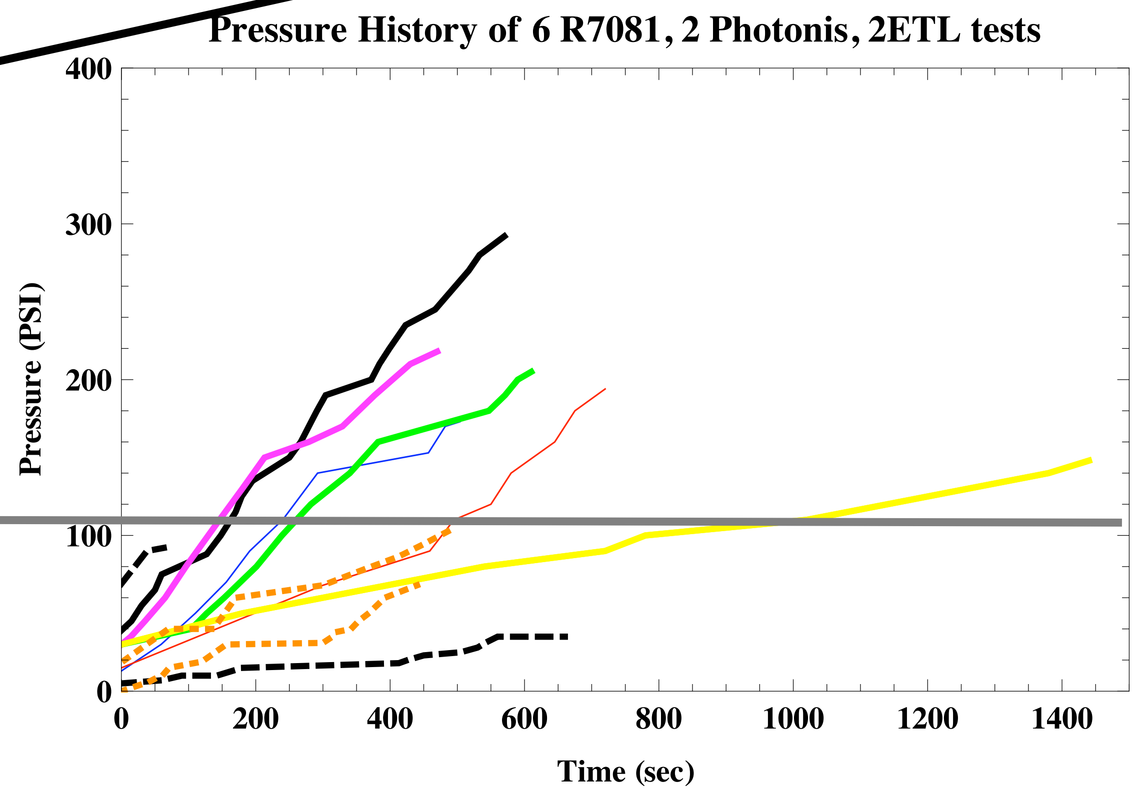
TA3090-140psi



start at high stress area ?

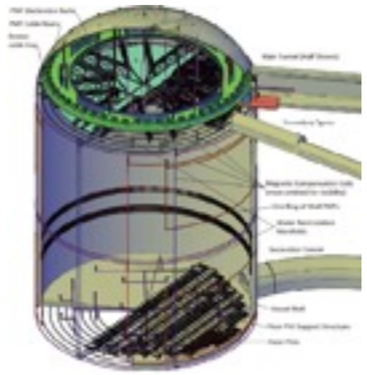


with base



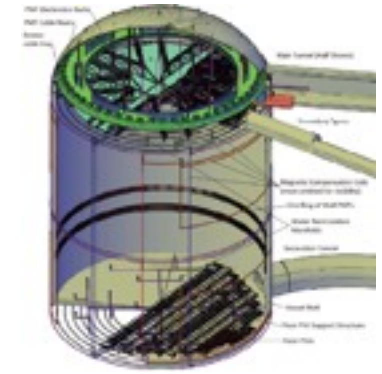
110

Data on static loading



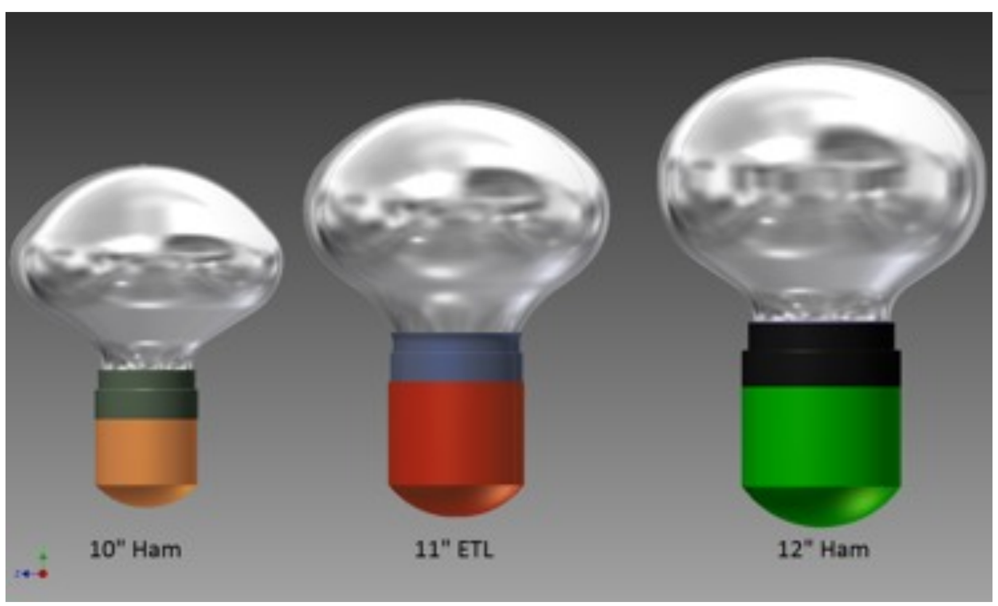
- Still low statistics, but have learned a lot.
- Each test preceded with detail measurement of thickness and flaws. No correlation yet found.
- Base encapsulation is crucial for further testing.
- The loading rate may affect the ultimate performance.
- Detail ANSYS modeling has resulted in showing that a more spherical dome shape will result in higher performance.
- Have tested one R11780 to 300 psi with no failure.
- We have more R7081, R11780 and ETL D784KFLB. Will start on this in December. Statistics: ~dozen each model.

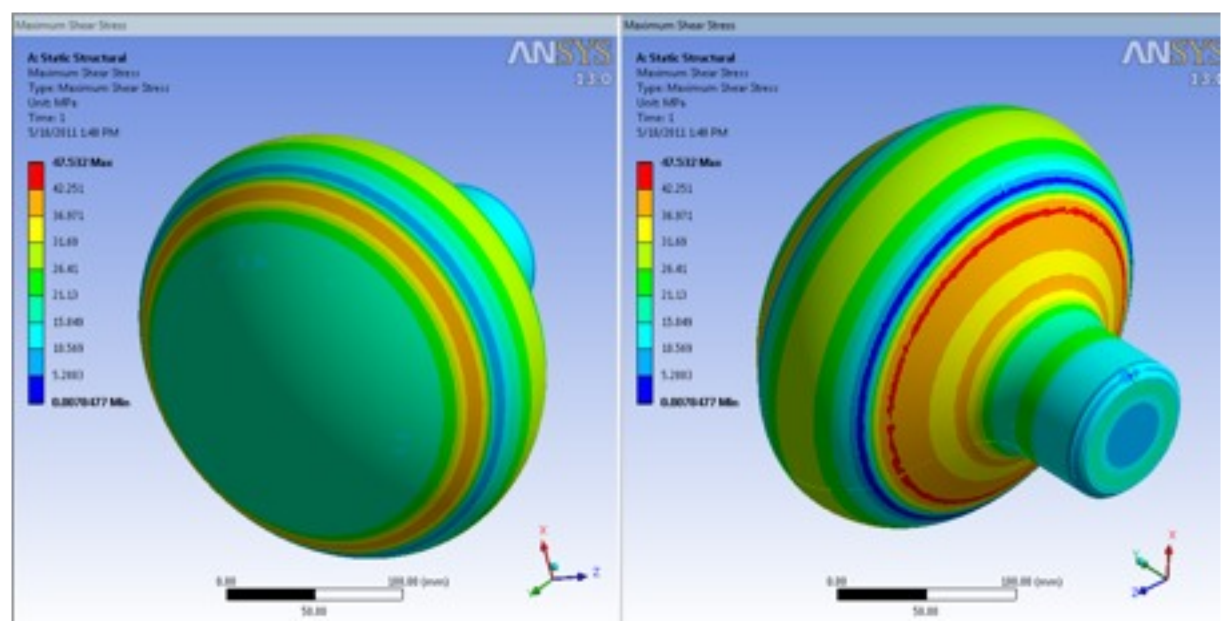
Modeling and new designs



BNL-PSL-base

D784KFLB





- Modeling has shown that the new designs have considerably less stress (esp. shear stress).

Glass Performance Over Time

- To design appropriate fracture mechanics tests to evaluate the PMT glasses from the vendors for neutrino detection
- To determine the time for failure of PMT bulbs at appropriate confidence levels based on well-established fracture mechanics data and statistical analysis
- To test the chemical corrosion in neutrino detection environment (e.g., at 14°C under 108 psi hydrostatic pressure) and predict its impact on the time for failure of PMTs
- To improve the mechanical properties of the PMT glasses for this application
  - Strengthen the current PMT glass composition
  - Formulate new PMT glass composition

This is pure R&D

Alfred University
The Sundaram Group

Major Challenges

- New PMT bulb design for the Long Baseline Neutrino Experiment Collaboration (LBNE)
- Limited glass strength/fracture mechanics data in the literature for PMT glasses - One need to collect basic datasets to perform required statistical analysis to predict the time to failure accurately
- No strength/fracture mechanics data for PMT glasses under planned conditions of LBNE
- Prototypic testing is cost prohibitive.
- Limited data on chemical durability of PMT glasses and no data for service under the conditions for expected LBNE campaign period of 20 years.

Alfred University
The Sundaram Group

Our Approach

- **Laboratory Testing:**
  - Flexural strength measurements for basic comparison only (Note: Flexural strength alone is not enough to fully evaluate the mechanical properties of the PMT bulbs) – Alfred University
  - Indentation measurements to collect basic fracture mechanics data to predict failure time – Alfred University
  - Detailed static fatigue testing to collect advanced fracture mechanics data to predict failure time – Alfred University
  - Proof-testing to report at appropriate confidence level – Alfred University
  - Accelerated chemical durability testing – Alfred University

Alfred University
The Sundaram Group

Progress Made

- **Laboratory Testing:**
  - Flexural strength measurements for basic comparison only (Note: Flexural strength alone is not enough to fully evaluate the mechanical properties of the PMT bulbs) – Alfred University – ***Preliminary results available***
  - Indentation measurements to collect basic fracture mechanics data to predict failure time – Alfred University – ***In progress***
  - Detailed static fatigue testing to collect advanced fracture mechanics data to predict failure time – Alfred University – ***In planning***
  - Proof-testing to report at appropriate confidence level – Alfred University – ***In planning***
  - Accelerated chemical durability testing – Alfred University – ***In planning***

The Sundaram Group

Flexural Strength – Sample Preparation

- The glasses were remelted and rods were formed by cane-pulling method.
- The glass rods were separated into three sets, each to receive differing treatments before strength testing.
  - The first set of 30 rods was left untreated.
  - The second set, 15 rods, were treated in a Potassium Nitrate (KNO_3) bath at 470°C for 24 hrs.
  - The third set, 15 rods, were treated similarly at 480°C for 24 hrs.
- The average modulus of rupture of the untreated samples was calculated to be 312.87 MPa, the rods treated at 470°C averaged 495.11 MPa, and the third set treated at 480°C had an average MOR value of 402.85 MPa.

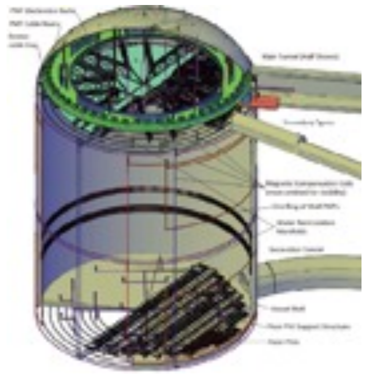
Alfred University
The Sundaram Group

Summary of work on glass testing.

- Currently, we are focused on collecting all fracture mechanics data on the glasses needed to calculate the time for failure of the PMT bulbs.
- Proof testing will be needed to support the time for failure data at required confidence level. There are standard industrial methods.
  - Proof-testing of all PMT bulbs is the best option, but it is cost-prohibitive.
  - In lieu of that, selected segments of the PMT bulbs will be used for proof-testing and statistical analysis.
- We plan to use vapor hydration testing (designed originally to evaluate nuclear waste glasses) for accelerated testing of PMT glasses for chemical durability.

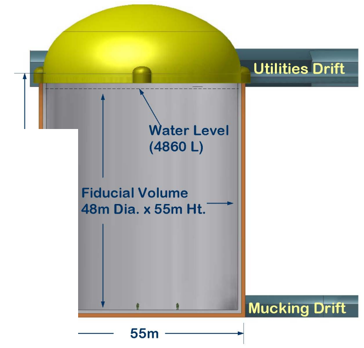
Alfred University
The Sundaram Group

Chain reaction testing and mitigation.

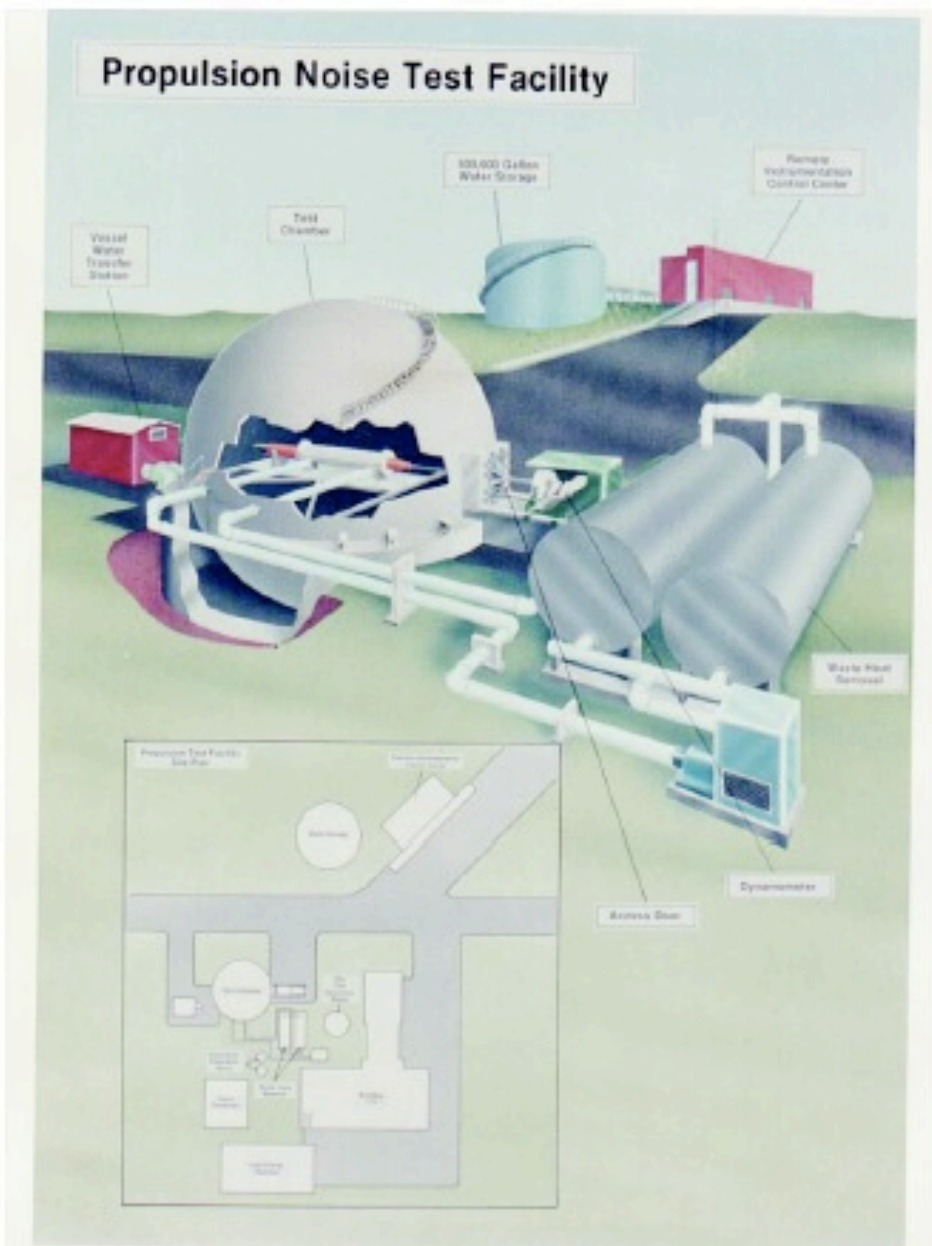


- Implosion of one tube will create a shock wave under the large water head and could cause other tubes to implode.
- Work is in 3 parts
  - Obtain information on a single PMT implosion and compare to simulation (completed Dec. 2010)
  - Perform multi-PMT events to understand the dynamics and simulation. (scheduled in 2 weeks)
  - After completion of the design for PMT housing, perform final design verification testing.

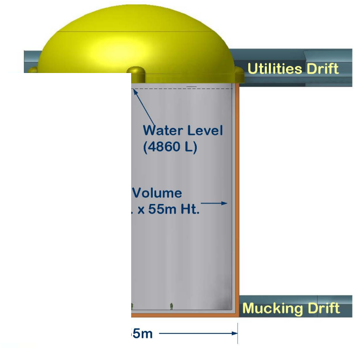
The work is coordinated with design work at Physical Sciences Lab. in Wisconsin and other collaborators



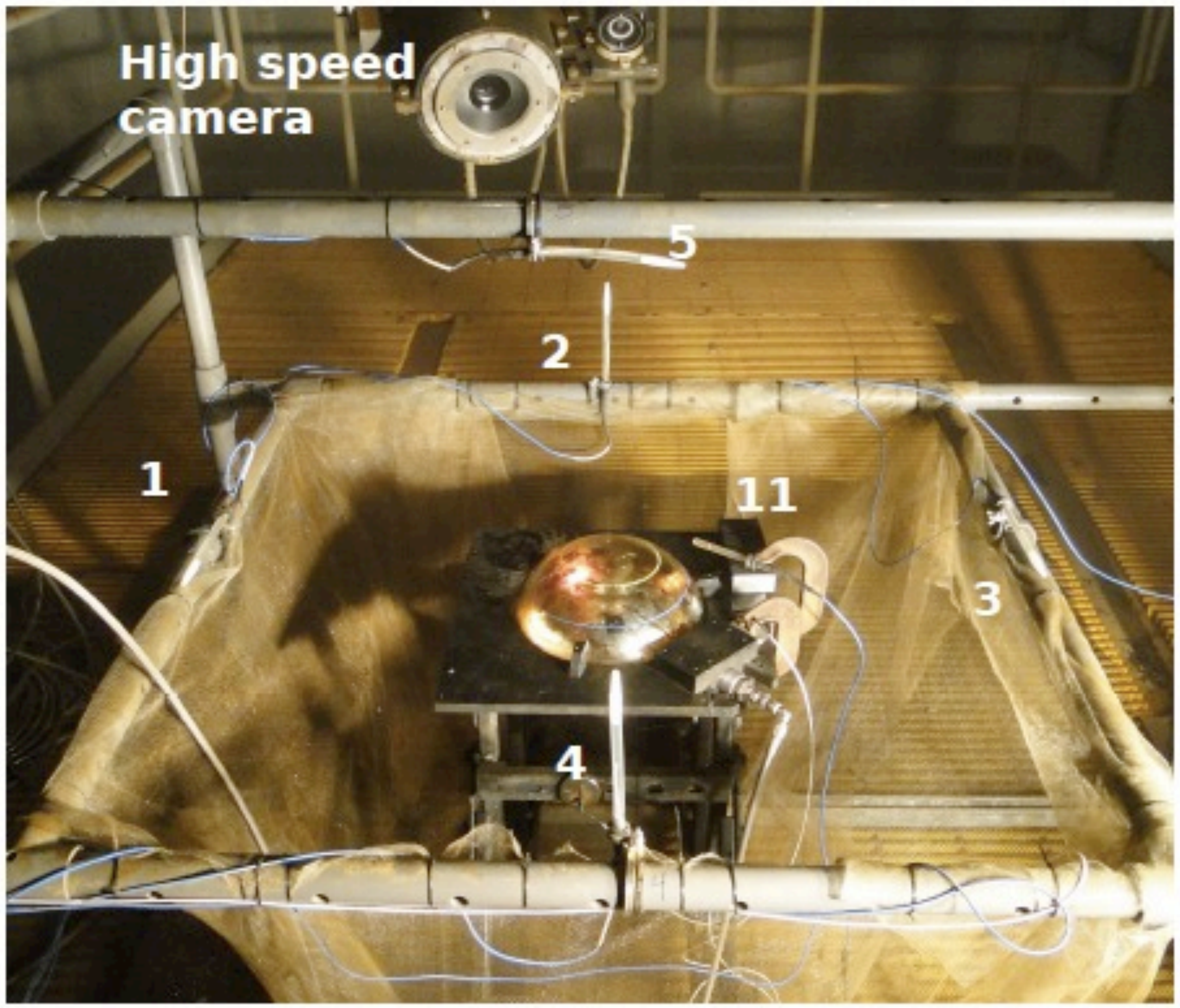
Navy Undersea Warfare Center (NUWC) Facility

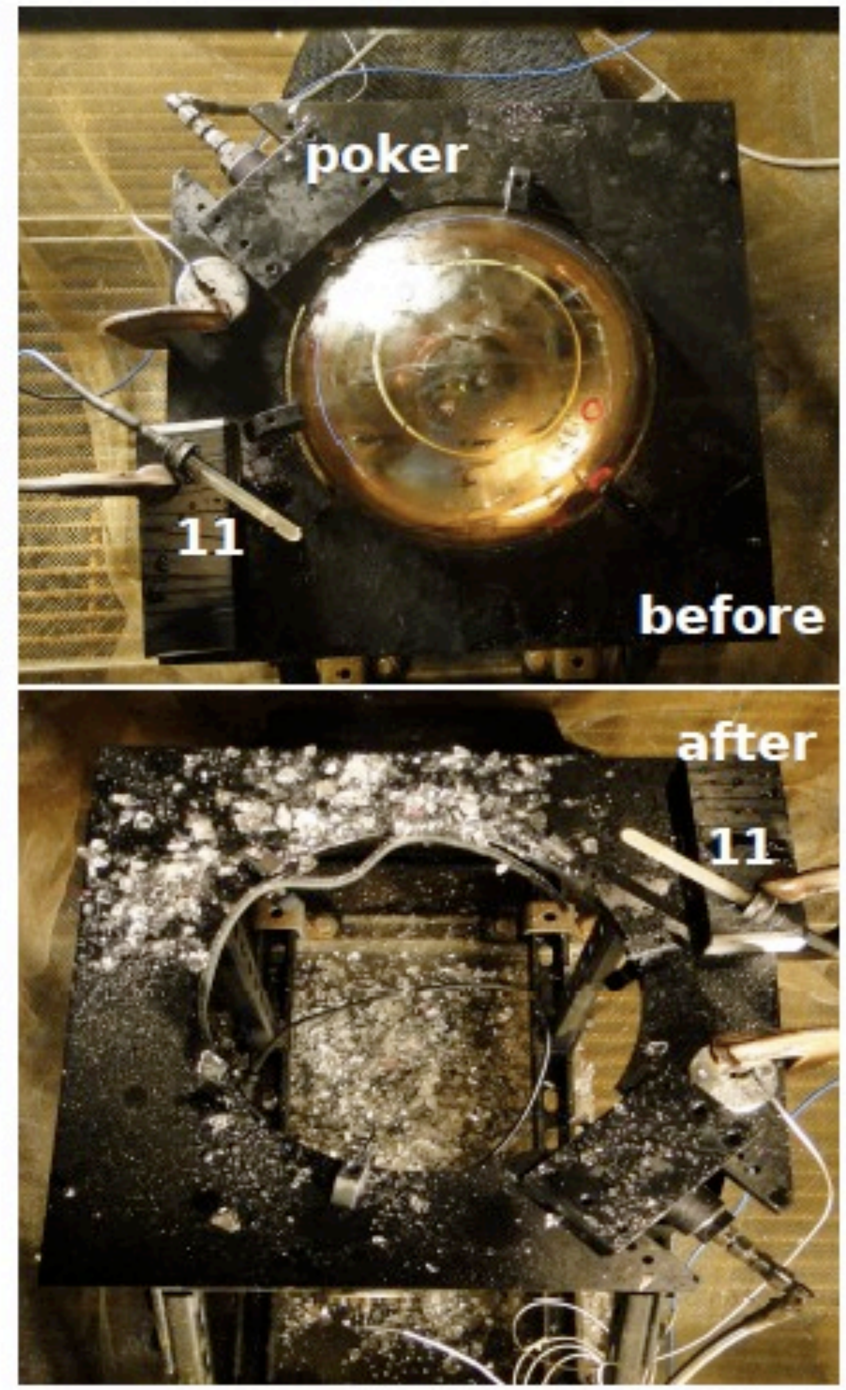


- Cooperation between BNL and NUWC through Cooperative Research And Development Agreement (CRADA)
- 15m diameter
- 500,000 gallons of water
- Rated for 100 psi at the center

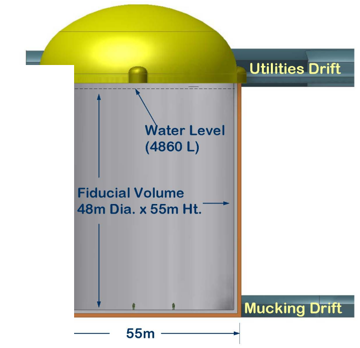


Experimental Setup

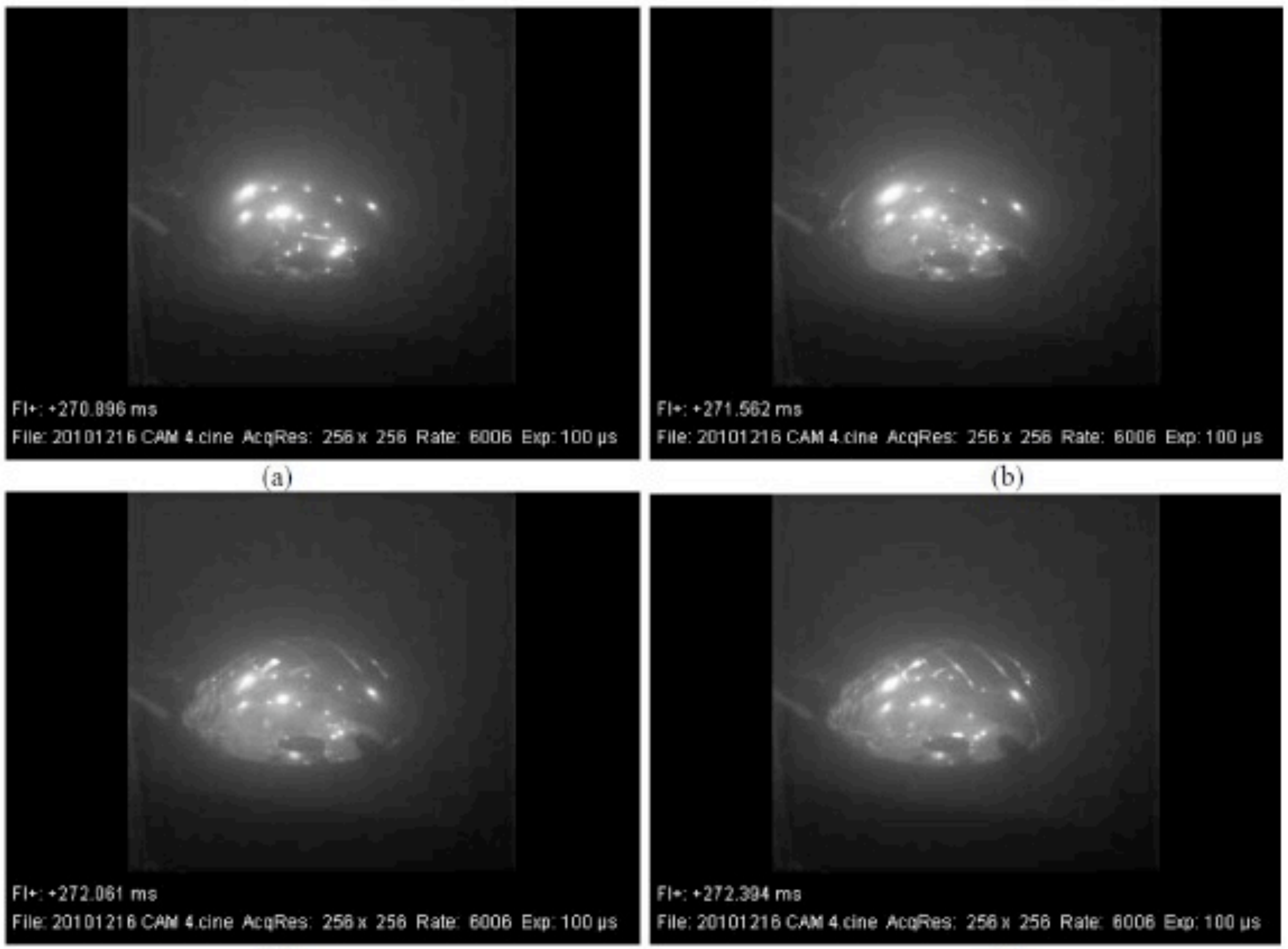




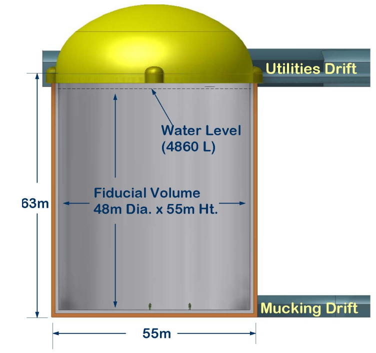
7 Water proof pressure sensors (PCB ICP)
4 Accelerometers
2 High speed cameras



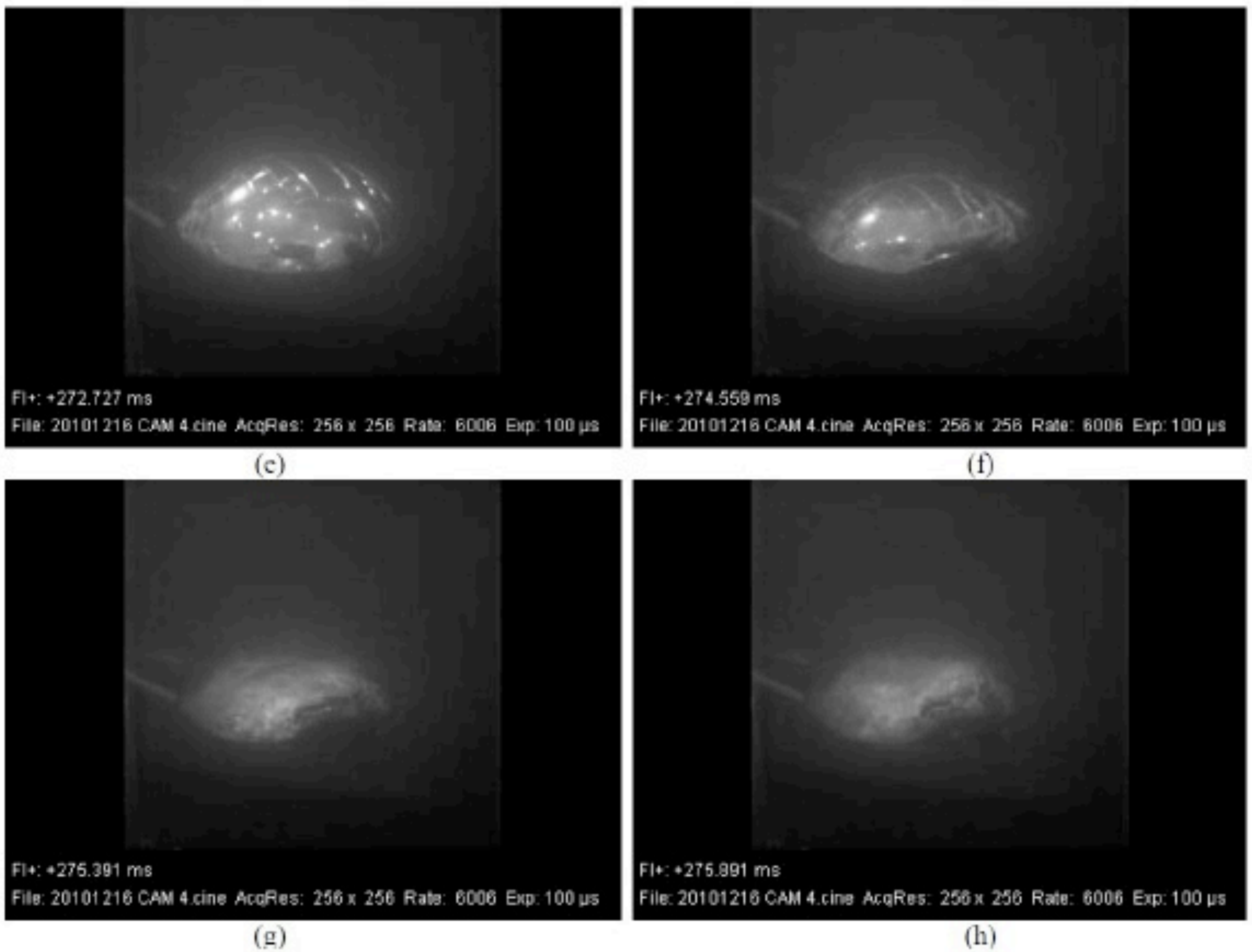
12/16/2010 Implosion Test

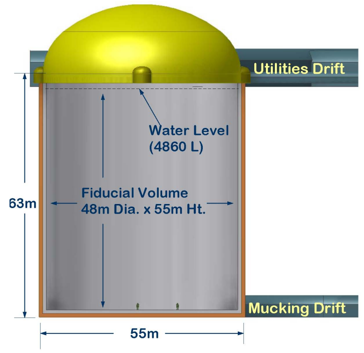


(a) (b) (c) (d)

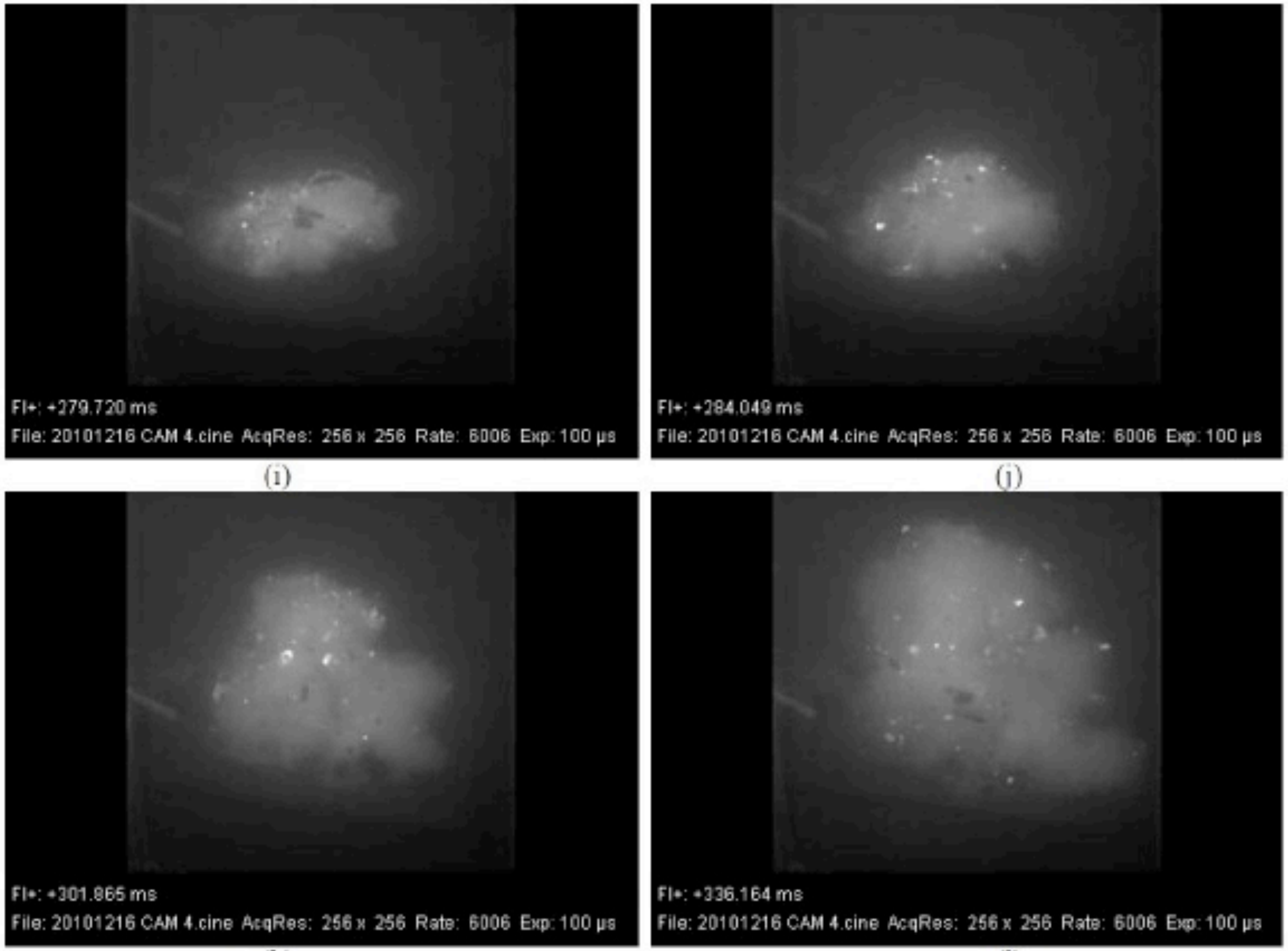


12/16/2010 Implosion Test

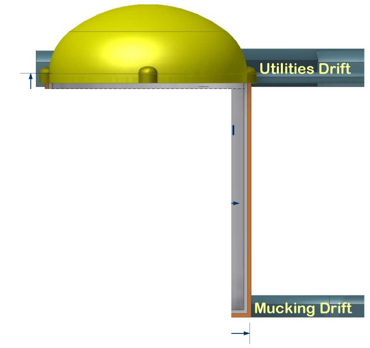




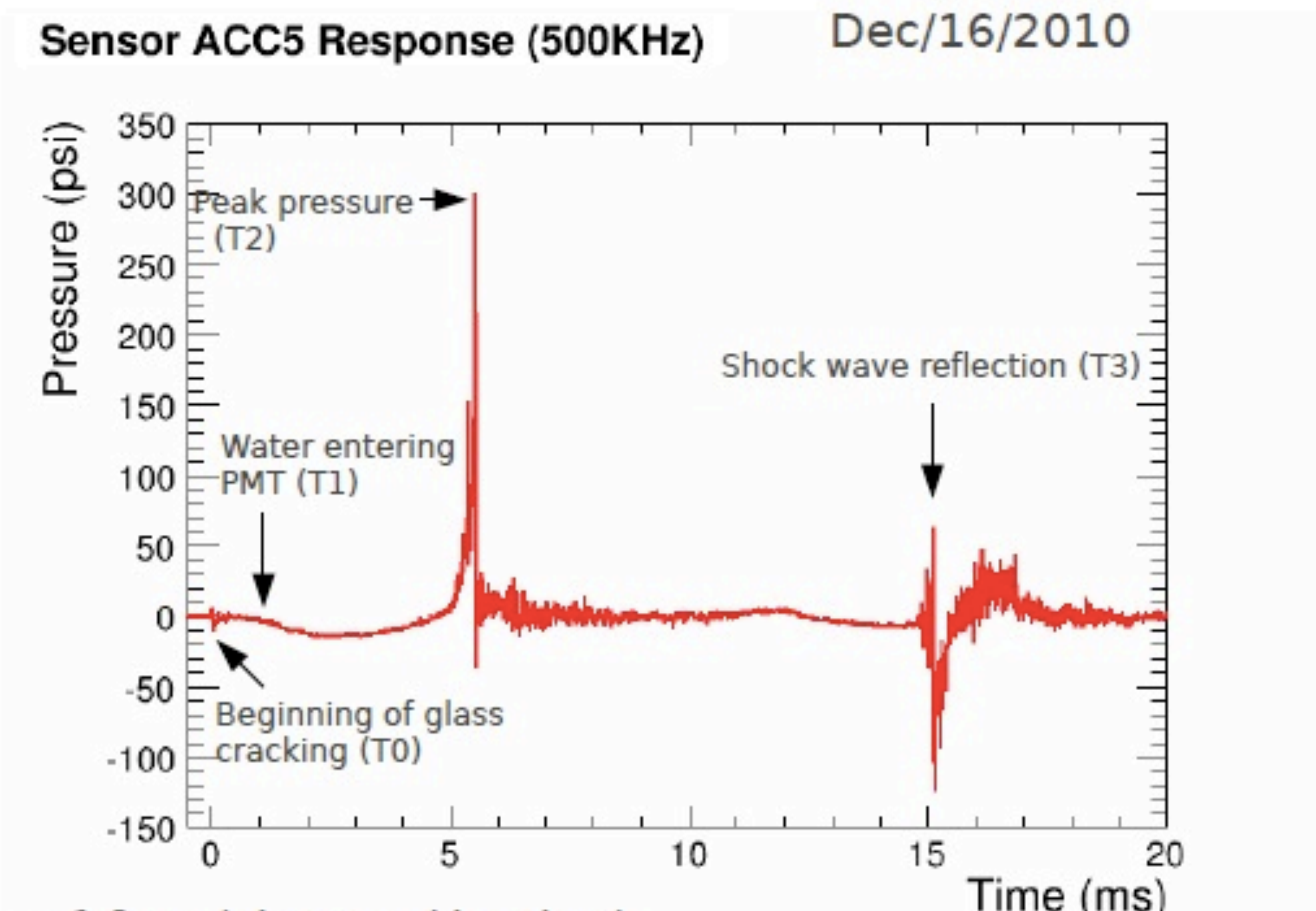
12/16/2010 Implosion Test



(i) (j) (k) (l)



Blast Sensor Pulse Structure



T1 – T0 ~ 1.0ms (glass cracking time)
T2 – T1 ~ 4.5ms >> 0.8ms (sound traveling time)
T3 – T2 ~ 10 ms (close to the speed of sound)

2．解析結果

Reminder: SK has 50 cm tubes, they found T2-T1~10ms

Some numbers SK simulation

20 inch tube

Pulse amplitude at 50 cm simulated to be 13.6 MPA

width >0.05 ms

Time of pulse 10.8 ms

Velocity of water at 50 cm

5.3 m/sec

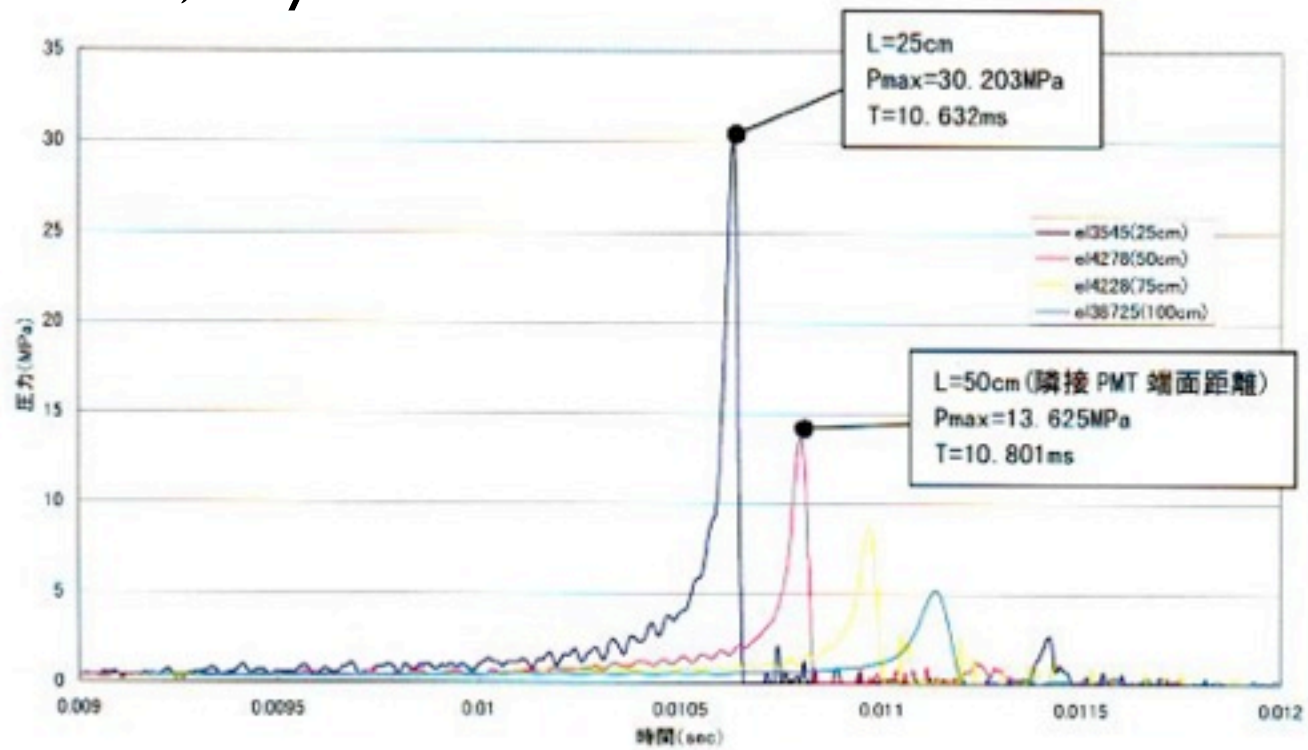


図-3　圧力時刻歴

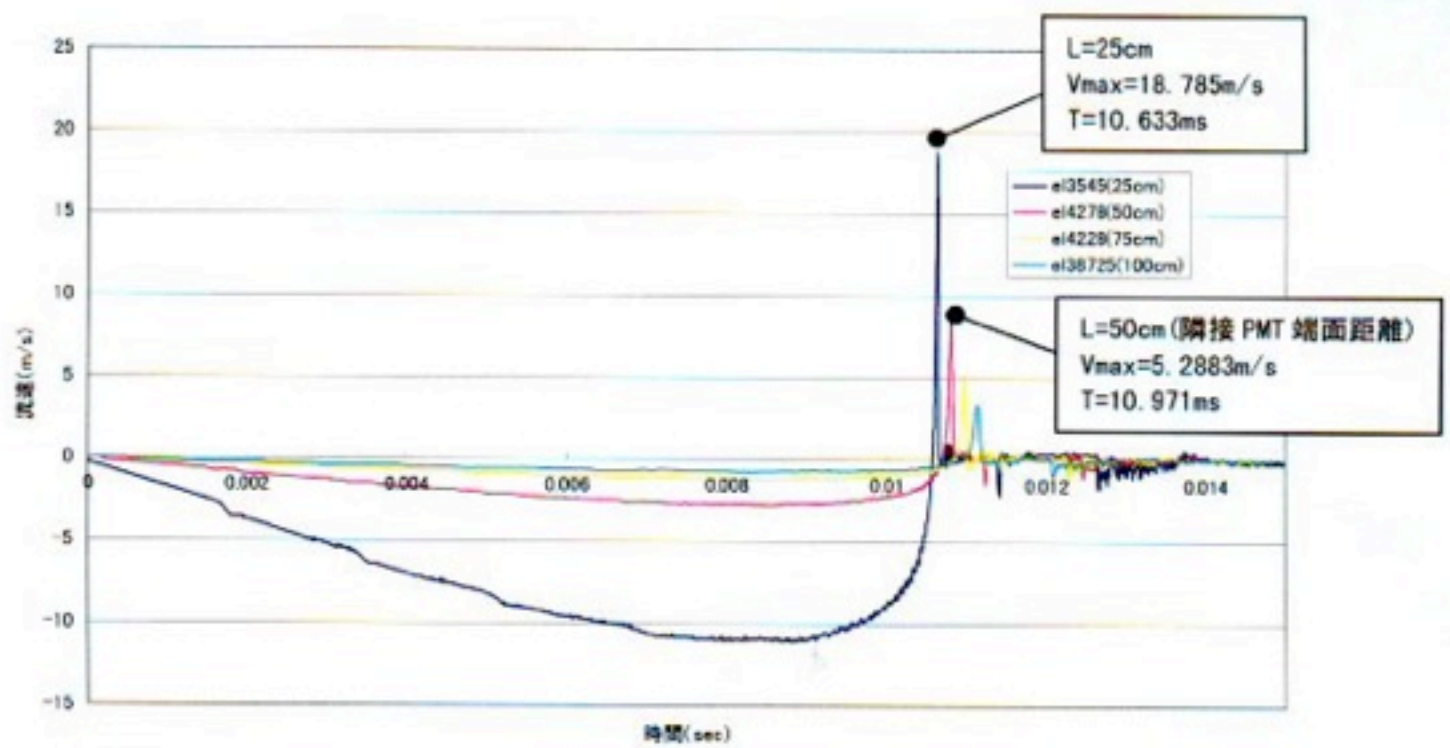
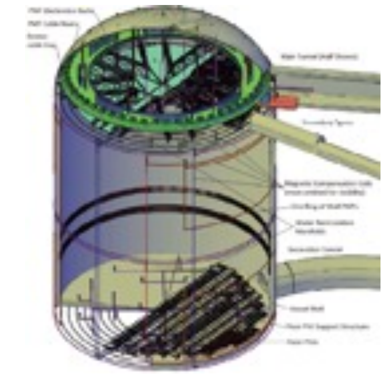
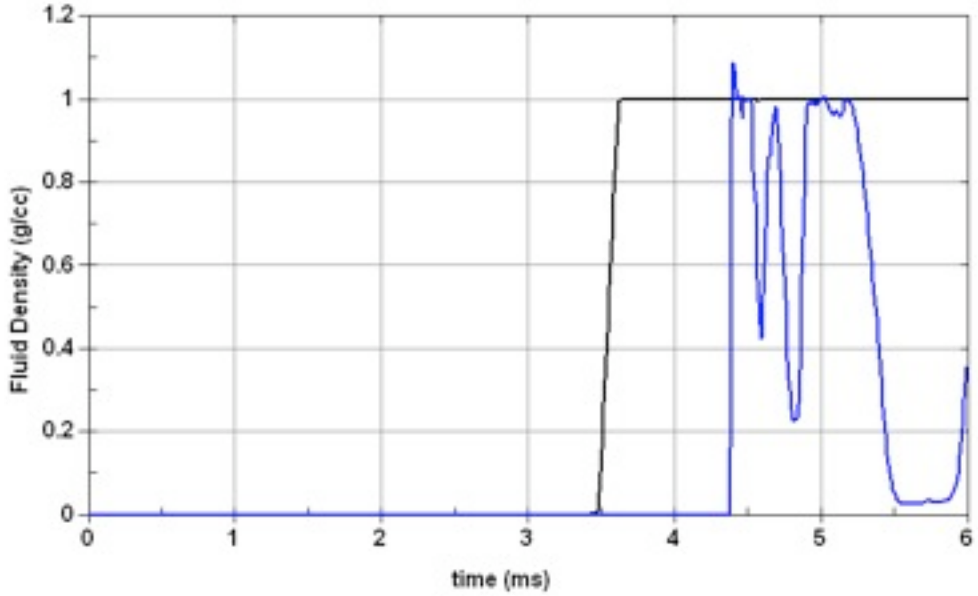
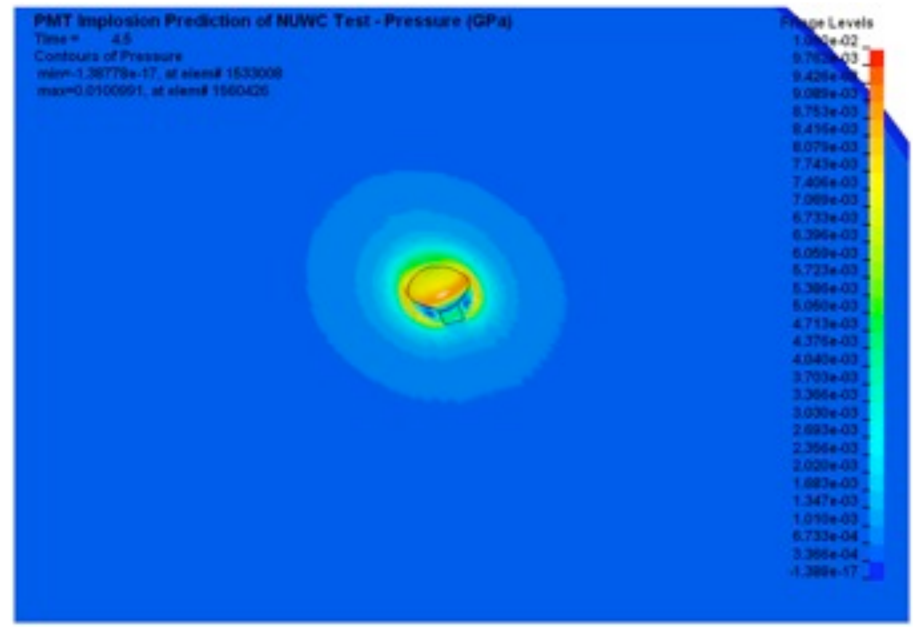


図-4　流速時刻歴



Simulation with LS-DYNA

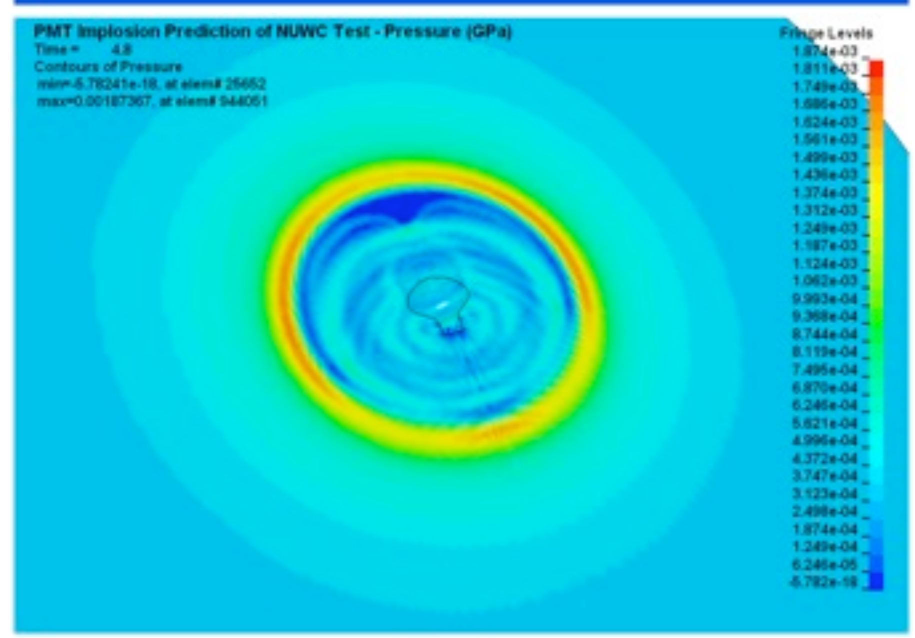




Pressure:

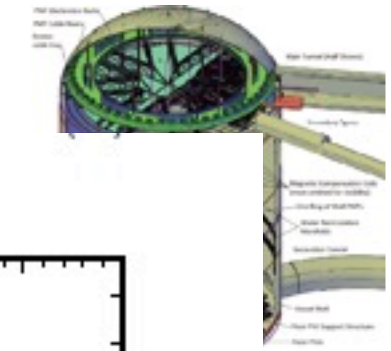
4.5 ms

density
4.41 ms



4.8ms

- We simulated the single PMT implosion with commercial multi-physics code at BNL.



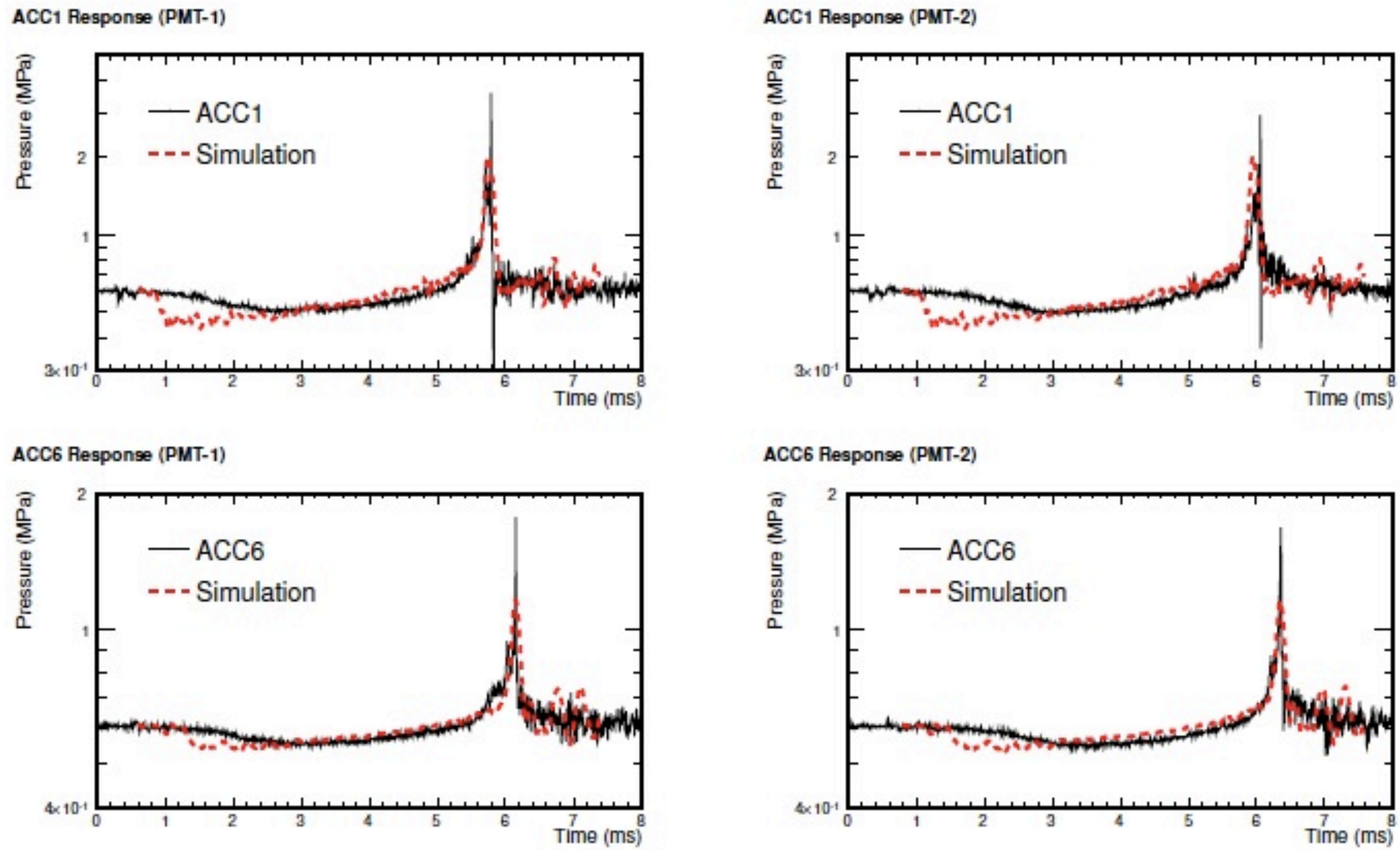
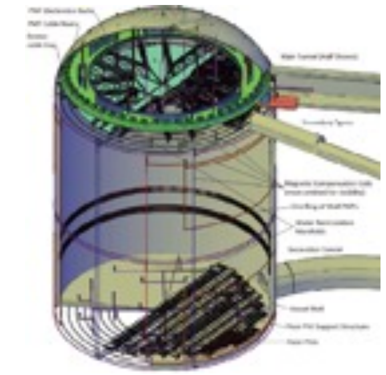
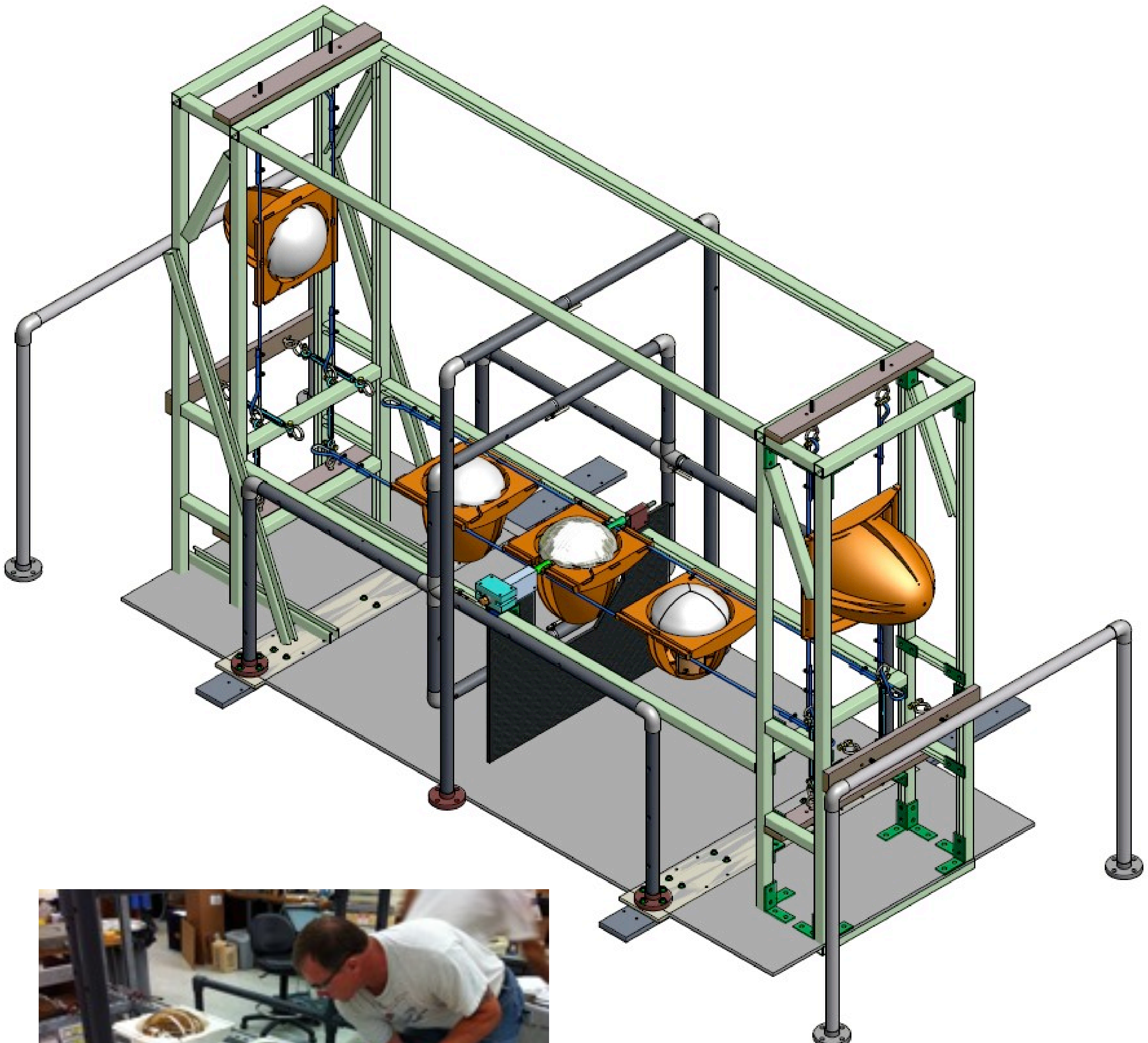


Figure 10: Comparison between the simulated pressure pulse and the tests results at the locations of pressure sensors. The time of the simulation results were adjusted so that the times of the pressure peak match for the sensor closest to the PMT. Left figures are for PMT-1, and right figures are for PMT-2.

Next step

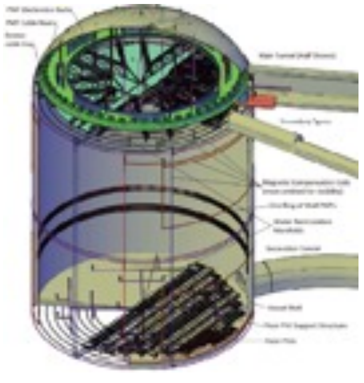




Will be more heavily instrumented

- Almost completely setup.
- Simulation in progress.
- Will test first ideas on PMT housing.
- The effect of a 4 micro-sec pulse at several MPa needs empirical demonstration.

Conclusions



- LBNE has a preliminary design for PMT housing for the water Cherenkov detector.
- Vendor interaction and in-house testing and calculations has resulted in confidence for future tube rating of >10 bar.
- Detailed proof testing is being designed.
- Glass is being examined by experts at Alfred.
- We have learned the dynamics of the implosion in detail and can simulate it.
- A lot of work in the next 6 months: full scale implosion chain testing, low statistics proof testing, and glass testing