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BooNE Technical Note 55

Assessment of the Risk of Tube Implosion at MiniBooNE

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Abstract

In response to the accident of Nov 12, 2001, at Super-K, the MiniBooNE experiment immediately began assessing the possibility of a chain-reaction tube-implosion within our detector. There are significant differences between MiniBooNE and Super-K. The MiniBooNE detector is a substantially more stable system. Based on information available from Super K and SNO as well as calculations done by the author and others, we can say with confidence:

- There is no threat to human safety from tube implosion in the MiniBooNE tank.
- If a tube implodes within the MiniBooNE tank, calculations show that this will not set up a chain reaction destroying further tubes. Our safety factor is estimated to be $> \times 2$.

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I What is known about the Super-K Design and Accident

The detector is cylindrical, 36 m tall and 34 m in diameter. It is filled with water. Hamamatsu 20-inch phototubes line the interior of the tank on a phototube support structure. They are spaced 0.8 m center-to-center to give 40% photocathode coverage in the tank. As with all phototubes, the interior is a vacuum. The tubes are rated by Hamamatsu for 6 atm of pressure. We believe that this does not represent the failure point – it is simply the highest pressure to which the tube was tested. For this discussion, we assume that the detector is at sea-level. Therefore, when full, the pressure is 4.5 atm at the bottom of the tank.

This paragraph describes our knowledge of the accident, so far. Most of this information is available from the Super K web page [1]. The tank was being refurbished at the time. Work for the day was completed and the tank had been closed off. At the time of the accident the detector was 2/3 filled with water. The implosion began with a singe tube, probably near the bottom of the detector. The reason for the initial implosion is not yet known with certainty. One possibility which has been suggested is that something within the detector near the region of recent work fell and struck the tube. While this is a plausible suggestion, it may not be correct and the actual cause may never be known. The initial implosion set off a chain-reaction. Reports indicate that most tubes below 5 m of the waterline were destroyed and the support structure was badly damaged. All tubes within 5 m of the surface of the water survived the implosion.

II Comparison of the Super-K Design to MiniBooNE

MiniBooNE is a significantly smaller detector, which is spherical in shape and 12 m in diameter. We use 8-inch Hamamatsu phototubes which are rated to 7 atm. Again, we believe this represents the highest level tested rather than the ultimate limit of the tube. The tubes are spaced 0.55 m center-to-center within the MiniBooNE tank. MiniBooNE will be filled with oil, which is a factor of 0.9 less dense than water. MiniBooNE is at sea level. The absolute pressure at the bottom of the tank is, therefore, 2.05 atm.

III Conclusions Concerning Human Safety at MiniBooNE

All tubes are already mounted in the MiniBooNE tank and are inaccessible. The tank is now full of oil.. Since the filling process started, it has been impossible for a human to enter the MiniBooNE tank because the access is on the bottom, therefore, there is no danger to humans during or after the filling process from tube implosions.

IV Calculations Comparing Implosion Scenarios at Super K and MiniBooNE

Attached is a spread sheet which shows the calculations for a chain-reaction from tube-implosion for Super-K and MiniBooNE. We calculate the shockwave based on the stored energy in the tubes, assuming the pulse-length is the tube radius. It should be noted that the energy stored in the MiniBooNE tubes is over an order of magnitude less than the Super-K tubes. We are interested in the total pressure on a neighboring tube if an implosion occurs. This is the combined pressure due to the shock wave and the static pressure in the liquid. The tubes located at the south pole of MiniBooNE are under the greatest static pressure, therefore, we consider what will occur to neighboring tubes if one of these implodes.

We scale from the tubes which survived the Super-K accident. Recall that the tubes within 5 m of the waterline survived. Therefore, we compare the pressure in the shockwave for MiniBooNE at the bottom of the tank (12 m) for an 8-inch tube implosion to the pressure 5 m below the waterline in Super-K for a 20-inch tube implosion.

The pressure on the nearest neighbor in MiniBooNE is 0.45 of the Super-K case at the level where the tubes survived. This would indicate a safety-factor of two if the tubes in MiniBooNE were equally fragile as the Super-K tubes. However, we believe that the Super-K tubes are more fragile due to their large size. As a result, we are confident that we have a greater than ×2 safety margin within our detector. Therefore an accidental implosion of one tube will not produce a chain reaction.

V Explanation of Spreadsheet

- **Detector Parameters:**
  - Tube spacing: The relevant spacing for the calculation is tube center-to-neighboring-tube-edge because the shockwave is localized at the center of the tube and radiates outward to strike the edge of the adjacent tubes.
  - Tube Depth: We consider a tube depth of 5 m for Super K because that is the depth for which tubes survived. We use 12 m for MiniBooNE because that is the depth of the MiniBooNE tank.
- **Energy Release:**
  - Tube Volumes: Calculated From Hamamatsu data sheets (the tubes are elliptical rather than spherical).
  - Implosion energy release: This is just $E = \int pdV$. The tubes are small enough that the pressure is assumed to be constant from top to bottom of the tube.
- **Pressure in Shock Wave:**
  - Shock wave radius: The center-to-edge distance ("Tube Spacing")
  - Shock wave length: The length of the shock wave is taken to be the radius of the tubes.
  - Shock wave volume: The shock is a spherical shell of radius given by the "shock radius" and thickness given by the "shock length."
  - Energy density (total): Total energy in the shock wave divided by the total volume of the shock wave.
  - Energy density (compressive): The energy in the shock wave is equally divided between kinetic energy of the movement of the water and the compressive energy of the shock itself. A theorem from hydrodynamics says that the compressive energy will be 1/2 the total energy.

- Shock wave pressure: This uses a standard formula relating compressive energy to pressure.

VI More Precise Calculations Comparing Super-K to MiniBooNE

A more rigorous hydrodynamic calculation was done by FNAL engineer Zhijing Tang [2] using numerical techniques. From these calculations a somewhat greater safety factor of 2.6 can be inferred.

VII Tests Done at Super K

After the accident a series of tests were done at Super K. The results and details of these tests have not been made public, however personal communication from several Super K collaborators to several BooNE collaborators indicate the following points:

- The test setup utilized nine 20-inch tubes in a rectangular array. The center tube was mechanically punctured.
- A high speed video camera was used to record the tests.
- At a depth of 30 m all nine tubes imploded in a chain reaction.
- At a depth of 15 m no chain reaction ensued.

Since the pressure at 15 m of water is significantly greater than the pressure at the bottom of the MiniBooNE detector, this supports the conclusion drawn from the calculations described above.

VIII SNO Weighs in

The Sudbury Neutrino Observatory [3] is also a water Cerenkov detector, using 8-inch Hamamatsu PMTs nearly identical to those in our detector. They of course have the same concerns as MiniBooNE, as well as the additional concern for the safety of their acrylic inner vessel that contains their heavy water. In 1990 a series of tests were performed at Queen's University [4] in a water-filled pressure vessel. In these tests four 8-inch tubes were mounted at an eight inch center-to-edge spacing (much closer than our tubes). The water was pressurized and one tube mechanically punctured. No chain reaction occurred at an average pressure of 6 atm, three times the pressure in the MiniBooNE detector. This test also supports the conclusion that we have no danger of a chain reaction resulting from a phototube implosion at MiniBooNE.

IX Conclusions

Since there is no possibility of human access to the inside of the MiniBooNE detector now that it is full of oil, there is absolutely no threat to human safety should a PMT in the detector implode. Furthermore, calculations based on what is known from the Super K accident, further tests at Super K, and tests done by the SNO collaboration all support the conclusion that there is no risk of a chain reaction in the MiniBooNE detector.

References

[1] C. Yanagisawa, T. Kato. *Report on the Super-Kamiokande Accident.* 22 November 2001

[2] Z. Tang. *Pressure Wave from Collapse of a Vacuum Cavity in Liquid.* MSG-EAR-01-307, 4 December 2001

[3] T. Bowles et. al. *Report on consequences of a SNO PMT imploding.* 21 March 2002

[4] C. A. W. Hearns et. al. *Report on Implosion Tests Carried Out at Queen's.* 14 August 1990

Crude Calculation of Pressure Spike from Underwater Photomultiplier Implosion

phototube radius. The hydrostatic pressure in this shock wave is evaluated at the radius where it reaches the nearest–neighbor photomultiplier tube.)				
DETECTOR PARAMETERS		**BooNE**	**SuperK**	
Tube radius	m	0.10	0.25	
Tube Spacing	m	0.45	0.55	Center to edge spacing.
Tube Depth	m	12	5	SuperK tubes at 5 meter depth survived.
ENERGY RELEASE FROM PHOTOMULTIPLIER TUBE IMPLOSION				
Water(Oil) Pressure (rho*g*h)	Pa	206840	150000	Absolute pressure at bottom of tank
	Atm.	2.05	1.49	
Tube Volume	m^3	0.0037	0.0590	More accurate volumes for BooNE & SK
Implosion Energy Release	J	765	8850	= (water pressure)*(PMT volume)
PRESSURE IN SHOCK WAVE AS IT PASSES NEAREST–NEIGHBOR PHOTOMULTIPLIER TUBE				
Shock Wave Radius	m	0.45	0.55	radius of spherical shockwave as it passes neighbor tube
Shock Wave Length	m	0.10	0.25	pulse length of shock wave (assume = tube radius)
Shock Wave Volume	m^3	0.20	0.58	volume of shockwave pulse as it passes neighbor PMT
Energy Density(total)	J/m^3	3787	15159	total (kinetic + hydrostatic) energy density inside shock wave
Energy Density(compressive)	J/m^3	1893	7579	hydrostatic energy density (=1/2 total)
Shock Wave Pressure	Nt/m^2	2610727	5774923	compressive energy = 1/2*vol*Pressure^2/modulus
	Atm.	**25.8**	**57.2**	**MiniBooNE tubes feel less than half of what**
				Surviving SK tubes experienced.
WATER/OIL DATA				
Density of Water/Oil	kg/m^3	900	1000	
Bulk Modulus of Water/Oil	Nt/m^2	1.80E+09	2.20E+09	www.quakerchem.com/solutions/brochures/quintolubric%20bro.1.pdf
Speed of sound	m/sec	1414.2	1483.2	http://230nsc1.phy–astr.gsu.edu/hbase/sound/souspe2.html#c1