1 Question 5

What are the safety considerations related to moving a detector full of scintillator on the surface?

A. Trailer Overturning

The detectors will be constructed and filled within the Braidwood site. They are too large for overland shipping, even with special permits. The detectors will be moved, slowly, on special rigging trailers. These trailers have independently controlled hydraulic arms for each set of wheels, to keep the load level independent of the grade surface. Here is a picture of such a trailer, carrying a 800,000 pound transformer:

B. Catastrophic Rupture in a Traffic Accident

Even though this move has much lower risk than, say, that of a gasoline filled tank trailer traveling over a public highway at high speed, we can, to put things in perspective, examine if our detector would qualify as a "cargo tank" under OSHA 49 CFR-Part 178. The code can be found at URL:

http : //www.setonresourcecenter.com/49CFR/Docs/wcd0000b/wcd00b3c.asp

The comparison shows that 49CFR requires a minimum wall thickness of 0.187" (4.75 mm). The Braidwood tank has a 6 mm wall thickness. The code allows stresses in the tank up to 25% of tensile strength of the tank material.

We have carried out a finite element analysis of the Braidwood tank and its supports by Fermilab engineer Ang Lee. This FEA analysis shows a maximum stress of less than 4200 psi in the walls of the sphere, with an allowable stress of 21,000 psi. This is only 20 % versus 25% allowable. The 49 CFR code also uses a "longitudinal deceleration of 2 g" The concern is pressure buildup at the front end of the tank at impact. This acceleration must not create stresses larger than 75 % of the ultimate strength. The Braidwood tank creates stresses of only 45% of the allowable stress.

We will determine definite maximum acceleration levels from a detector moving study that is an urgent component of our R&D proposal. Verbally we have been told that dynamic accelerations can be held routinely below 1 g. The stresses in the steel pads have a safety factor of 3, hence are good to 2 g dynamic. The stresses in the column legs have a safety factor of 2.25 and are good to 1.25 g dynamic. The last two items can be beefed up inexpensively to whatever safety factor is desired.

C. Risk of a Small Oil Spill

The detector is in a spherical tank. The tank has a large flange just above the equator. This flange will have an O-ring seal and will be bolted very strongly to resist shifting between the lower and upper hemisphere during handling. This seal is extremely unlikely to leak.

All penetrations are at the top, above the oil level which guards against leaks there. The oil volume is sealed with O-ring seals there, except for a small vent pipe to allow pressure equalization with the atmosphere and to admit inert shield gas to protect the scintillating oil from oxygen. The vent pipe reaches well above the oil level and will have a small phase separator canister for additional protection against small spills.

D. Rigging the Detectors Up and Down the Shafts

We will use a professional and insured rigging company with documented experience in such moves. We expect to use a jacking system (subject to the moving study we hope to commission soon). The jack clamps are self-locking and require hydraulic pressure to open. The system is always in a safe state even when all power is lost during rigging. Redundant steel cables will be used to protect against cable failure. No personnel will be allowed below the load at any time.

2 Question 8

Please provide some information that will indicate the ruggedness of the engineering to make it possible to move the detectors between sites. How big are the expected dynamic loads encountered during movement compared to the static loads that enter for the normal engineering design?

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A. Detector Tank and Supports

Please see answers to question 5.

B. Acrylic Sphere

It is important to note two design requirements for the Braidwood Detectors:

a. Both the inner scintillating oil volume and the outer buffer region will be filled to the neck area. The neck has relatively narrow fluid channels, connecting to overflow spaces above the tank. Hence, there is no room for oil sloshing even if some lateral accelerations should occur (the overflow space will have perforated anti-sloshing separators, as are commonly used in cargo tanks).

b. The density of the mineral oil in the buffer will be carefully and precisely matched to the density of the scintillating oil in the inner zone. This is necessary to limit hydraulic forces (weight and accelerations) on the acrylic sphere. The dry weight of the acrylic sphere is 1200 kg. This force must be supported, with a safety factor, before the oil filling. By matching the oil densities, this force will decrease to less than half, due to buoyancy. This makes the acrylic spheres and its supports capable of resisting accelerations in excess of 2 g total. Our preliminary design for the supports system of the acrylic sphere meets that 2 g requirement in all directions.

C. Photomultiplier Protection

Following the photomultiplier (PMT) implosion incident at Kamiokande, the Miniboone collaboration careful analysis was carried out by Len Bugel for presentation to the Fermilab Directorate.

The most credible event would be an acceleration of the detector tank during a move, creating a pressure wave. The pressure wave would, somehow, destroy a PMT. The shock wave from that PMT would destroy more PMT's. Note that the R5912 PMT's are rated to 7 at pressure. A dynamic acceleration of (7at)/(1.6at) = 6.25 g would be required to reach that pressure.

The SNO experiment did a test with four 8" PMT's (same as Braidwood PMT's), mounted with 4 inch separation, and subjected to 6 at water pressure. One tube was punctured mechanically. The remaining PMT's were not damaged. The energy released from the punctured tube was the tube volume times (6+1) at. At the close test spacing (8 inch center to rim of next tube) versus the Braidwood spacing of 12 inch , the energy density is down a factor $(8/12)^3 = 0.3$ We can now derive a safety factor for Braidwood of (7 at) / (1.6 at) times (1/0.3) = 14.6