Some Technical aspects of the SNO bladders

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The bladders proposed for use in SNO (see "Simultaneous NC, ES, CC solar-neutrino detection using salt-filled bladder with SNO", by Ron Schubank, SNO-STR-90-50) as salt barriers are thin, transparent,inert films are of two main types:

1) 12m diameter, to act as an in situ reservoir during de/salination and/or emergency "bandaid" to plug small leaks in the main acrylic vessel

2) 10m diameter, to act as an additional detection region, allowing simultaneous ES,CC and NC monitoring, by separating an (n,gamma) salt (eg NaCl of Gd) on the inside from an (n,alpha) salt (eg. H3BO3) outside. This would physically remove spurious d(n,gamma) events from vessel and exterior radioactivity.

The bladders would also possess a 1m diameter (or smaller) neck 8m high, as well as be equipped with tether points (min. 4 equatorial + 1 bottom) to facilitate bladder insertion/extraction into the main SNO acrylic vessel.

There are several candidate materials:

clear polythene
polypropylene
PVC
MYLAR
EVA
EPDM
SPECTRA (long chain CH2)
TEDLAR
TEFLON

Initial evaluation suggests that TEFLON FEP film is the most suitable candidate from a point of view of transparency, strength, thermal, mechanical properties, etc. This report will therefore concentrate on properties of a teflon bladder.

Teflon can be heat sealed, thermoformed, welded and heat bonded, greatly facilitating construction of a large diameter bladder. It has a wide thermal range, with continuous service between -240 to +205'C. It is the most inert of all plastics and is naturally bio-attack resistant. It also possesses low permeability to liquids and gases. It is commercially available in clear UVT

...rm from 0.005" to 0.020" thicknesses. A high stress crack resistant (type-L) version is available from 0.005" to 0.090" thickness (for use in extreme environment).

Light transport
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Clear (UVT) teflon is effectively transparent over the wavelength regions of interest to SNO, 350-600 nm, with most of the reported transmission losses (4%) due to teflon-air refractive index mismatch. However, unlike most plastics, the refractive index of teflon is 1.344 +-0.003 which nearly perfectly matches that of heavy water; the impact on light signal detection within the bladder from the point of view of light absorbtion and/or rescattering is therefore entirely negligible.

Mechanical properties
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Property	Test Method	Typical Value (for 1mil @ 25C) SI units	Inch-Pound units
Density	ASTM D-1505	2150 Kg/m^3	134 lb/ft^3
Tensile Strength at break	ASTM D-882	21 N/mm^2	3000 psi
Elongation at break	ASTM D-882	300%	
Yield point	ASTM D-882	12 MPa	1700 psi
Elastic Modulus	ASTM D-882	480 MPa	70000 psi
Impact Strength	DuPont pneum.	7700 J/m	144 ft-lb/in
Folding Endurance (MIT)	ASTM D-2176	10000 cycles	
Tear Strength -initial (Graves)	ASTM D-1004	2.65 N	270 gram force
Bursting Strength (Mullen)	ASTM D-774	76 KPa	11 psi
Melt Point	ASTM D-3418(DTA)	260-280'C	500-536'F
Zero Strength temperature	(*)	255'C	490'F

(*) temp.at which a film supports a load of 0,14 N/mm^2 (20psi) for 5 seconds

Choice of thickness
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The primary concerns in choosing thickness are

1) radioactivity levels (U & Th)
2) fabricating ability

3) mechanical strength

Sample material is on order for radioactivity assay. It is expected to be comparable to levels found in the main acrylic vessel, that is of order few ppt U and Th; however this must still be verified. It is of course necessary that the contribution of radioactivity of the bladder be less than the main acrylic for the 6m diameter case, and less than the effect of the acrylic at one meter inside from the vessel wall; that is, less than the acrylic attenuated by an effective shielding of 1m of water.

A 10m diameter bladder (spherical only, not including neck) would weigh 17 Kg per mil thickness; a 12m diameter bladder would be 25 Kg per mil.

Fabrication ability at moment of writing may be of a concern, as the company that is willing to do the welding (Inflatable Images of Canada, Ltd.) has encountered difficulties with very thin (0.001") teflon film; thicker film, up to 0.020", is much easier to work with. However, the main problems of burn through may be removed with R&D on temperature & tooling control.

Mechanical Strength may be of some concern in the extreme case of the smaller bladder were required to support a large net load, say 1.5T of NaCl dissolved within the (heavy)water on the inside, with only 50Kg of H3BO3 outside. For the 12m diameter case, the strength is of less importance, as the bladder is in direct contact over almost all its area with the main vessel; the bladder need only be strong enough to survive handling during insertion or extraction and the stresses imposed while filling/emptying with (de)salinated (heavy)water.

To calculate the stresses, strains, shape changes and optimum support locations of such a heavily loaded, flexible bladder is not a trivial problem. Much research into this problem has been done regarding scientific research balloons, especially of the super-pressure type, where typical balloons are over 100m diameter, and are constructed of 0.00025" thick polyester panels 1m*1m bonded with kevlar reinforced tape; loads are attached to kevlar reinforced cables bonded halfway below the balloon equator. The balloon masses are typically several hundred Kg and are able to support a comparable load. Loading tends to deform the balloon shape from initially spherical to "tear-drop", countered somewhat by the effects of the reinforcing strips.

It would be highly desirable that the 10m diameter bladder be allowed to float with neutral density in order to minimize or even eliminate stresses & strains. If the small bladder were filled with, eg, 1.2T NaCl /500T D2O, then the region outside the bladder must be filled with 1.2T salt /500T D2O, where salt= pure H3BO3, or some H3BO3 with NaCl or other "inert" (both from radioactivity as well as neutron capture points of view) salt.

A more favorable situation would be to fill with 30Kg Gd inside and 50Kg H3BO3 outside. The Gd(n,gamma) spectrum is not as ideally suited to SNO as Cl(n,gamma) because of the lower average energy of the emitted gamma spectrum; however, there still remain the advantages of using Gd with the bladder from the onset, as well as reducing the strong (gamma,n) background between the bladder and the vessel, compared to the "conventional" salt fill - empty cycles. (Reducing the coincidence window to allow only hits from within R=7.5m coupled with physically reduced low energy background at R=5-6m could in principle allow running with a lower PMT threshold, thereby gaining back some efficiency)

For the extreme case where the bladder system must support a net load of 1.5T of NaCl:

net pressure exerted = 1.5T*g /(4*pi*R^2)= 50Pa,
=1/700 max. bursting strength for 1mil teflon

If bladder were supported only by the neck (assuming 1m diameter, although latest SNO design of 1m dia. for acrylic vessel neck may require smaller dia.) the Maximum tensile strength needed by the film near the neck
= 1.5T*g / (2*pi* 0.5m * 0.001")
= 40 MPa for 1mil film

which greatly exceeds the tensile strength of 21MPa for 1mil teflon. Clearly then, some kind of support and reinforcing would be required.

For the case of a support ring half way above the equator connected to Nylon-1212 or other appropriate cables, the Maxi tensile strength needed would be reduced to 5MPa for otherwise unreinforced film.

Further reductions can be made by increasing the film thickness and/or using reinforcing strips (akin to kevlar strips used in weather balloons). However, either solution will (greatly) increase the mass of the bladder system, and hence the radioactivity, as well as complicate fabrication.

Bladder insertion and extraction
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The 12m bladder will have one bottom and four equatorial tethering lines attached to it. The tethering lines would be looped through plastic pulleys mounted on the inside of the main acrylic vessel, ultimately leading outside the vessel. The 10m bladder would be similar, but may include several more lines attached to a reinforced, flexible (kevlar) ring half way between the equator and the top of the bladder if it is found necessary to run with a large net load of salt. Before insertion, the bladder is to be first neatly rolled along the polar axis to form a long cylinder-like shape so that it may be pulled through the main vessel aperture.

NOTE that only one bladder may be used at a time, because of the need for tethering lines to pull the bladder through and stabilize its position once inflated; however, it would still be possible to insert the larger 12m bladder first without resorting to the use of tethering lines, but its insertion then becomes much more complicated.

Also Note that the bladder prevents the use of "solid array" type neutron-to-gamma converters, such as the 3He counters, encapsulated 10B or 6Li loaded scintillator, or encapsulated NaCl, etc.

Conclusion
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The use of the bladder to act as an emergency patch, to accelerate desalination, or to act as an important third physical boundary for simultaneous NC monitoring is still a viable option for SNO. The last option could also prove useful in relaxing upper permissible radioactivity limits on the main acrylic vessel and the PMT assembly by reducing events originating from gamma induced fission of deuterium. The use of NaCl would require either large amounts of H3BO3 + inert salt to compensate the physical load in a thin (few mil) bladder, or the use of a thick (20 mil) and/or reinforcement + support assembly.