restricted to SNO

Summary Report on Acrylic Vessel.
by Davis Earle
Feb. 1998
SNO-STR-98-~~xxx~~ 005 (R)

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Panel & Bond Identification:

The vessel components have been identified by row and position in the row with respect to construction north. The rows are identified by letter with the chimney, row A, and the bottom plug, row K. The eight chimney components are number from one to eight with the top flange #1 and the collar #8. In each row the panels are labeled sequentially starting at construction north and proceeding east to south to west around the circumference. The RPT (Reynolds Polymer Technology) panel identification for each component in the vessel is shown in **Table 1**.

Bond identification follows the same pattern as panel identification. Each row of bonds is identified by a letter with the A bonds in the chimney and the K bonds in the bottom plug. In each row the bond just east of north is #1 and the identification increases sequentially towards the east, south and west. **Table 2** lists the RPT panels on either side of each bond.

Fig. 1 & 2 show the RPT panels in each row pictorially. Also shown in these figures are the location of various vessel repairs. There were short (several inches) slot repairs at the top of vertical bonds which were made in parallel with the corresponding horizontal bonds and several plug repairs which had to be made in horizontal bonds. These figures also show the approximate location of the vertical bonds with respect to those in the adjacent rows.

Properties of Polycast Panels prior to Construction.

The physical properties of the AV panels were measured at Polycast and at CRL prior to delivery to RPT. This information is in **SNO-STR-93-042** as revised and expanded Jan. 24, 1994.
The panels are identified according to the Polycast batch and sheet #. **Table 3** cross references the Polycast ID with the RPT ID. The following information is recorded in SNO-STR-93-042.

The minimum thickness of each panel as measured by Polycast. Their data sheets of their thickness measurements are on file.

The mechanical properties of each batch as measured by Polycast. They measured the tensile strength, the tensile elongation, the tensile modulus, the compressive deformation under load and the residual monomer. They also reported on inclusions in the sheets.

The optical absorption coefficient of samples from each acrylic sheet are also summarized in **SNO-STR-93-042**. A figure of merit was determined for each panel and that number is tabulated in **Table 3** for easy reference.

The T/U content of each batch was measured by neutron activation and gamma ray counting. In general five samples from each batch were measured. The results are tabulated in **SNO-STR-93-042**. The results of disequilibrium measurements utilizing alpha spectroscopy are also reported.

Panel selection for the vessel was based on this document. Vessel grade panels were selected based on the optical transmission data except that batch 80 panels were downgraded because of high Th/U content. The thicker panels were placed in the upper hemisphere and the thinner ones in the lower hemisphere with the thickness panels in the 110 row next to the chimney.

Syrup Verification

Over a hundred batches of syrup were mixed and used in the vessel construction. A small portion of the syrup was used to made a test block. After thermoforming, five dog bones were machined from the block and the tensile strength of each sample was measured. The minimum and maximum tensile breaking for each set of samples is recorded in **Table 4.** In almost all cases the samples broke above 8000 psi. No batch was found to be unsatisfactory. However several test samples were incorrectly prepared and new test blocks had to be poured before the syrup could be used. No syrup was used in the vessel before the test results for that batch had been received by Brewer or Earle. The detailed test results are on file. The design specification required the syrup to test at greater than 4000 psi. No batch was even close to such a low value.

Polarized Inspection:

All the bonds were inspected for stress with polarized light. This inspection integrates over the thickness of the material and does not detect local surface stress should they exist. Initially, for the chimney bonds, photographs where taken of each bond. The UBC group videoed the bonds in the upper hemisphere except for the 108/110

horizontal and the repairs to the 110 verticals. The remaining bonds were videotaped or inspected visually and the number of fringes seen were recorded. Photos were taken, if more than two fringes were observed and, of the repairs.

Davis Earle looked at the two video tapes of upper AV bonds and selected 14 T joints for still photos. The UBC group photoed these May 29/1996 day shift. The T joints photoed are listed below. Seven were selected as the worse of the lot and are identified in the table. (Six are shown on the accompanying page of photos, **Fig 3**). On June 5th four of these six were inspected visually by Jerry Stachiw and Hugh Evans who also rephotographed D11. They all appear to have 6 to 7 fringes in the photos and this was confirmed by visual inspection.

Bond #		
D6	106-13/7 top	
D11	106-2/5 top	hazy bond, inspected visually, seemed normal, re photographed
D5	106-7/12 bottom	
D4	106-11/12 bottom	
E9	104-4/6 top	7 fringes, inspected visually, repair 1/4" deep
E13	104-1/5 top	unusual fringe pattern, 3/4" by 3/4" triangular repair, inside
E3	104- 10/11 top	7 fringes, repair 3/8" deep
E10	104-3/4 top	5 fringes, repair 1/8" deep
E9	104-4/6 bottom	
E7,F11	104-13/8 bottom & 101-1/102-8 top	
F18	102-6/101-7 top	7 fringes, inspected visually, repair 1/2" deep
F20	102-4/101-6 top	
F2	102-2/101-4 top	
F7	101-9/102-9 top	
F16	102-7/101-10 top	7 fringes, inspected visually, repair 3/8" deep
F1	102-4/101-4 top	

On Dec 12, 1996 Davis reexamined the videos and confirmed that the 110 verticals had been checked, except for the two slices which replaced the 110-7/109-5 and 109-11/110-4 bonds. Photos were taken of selected regions of the 110/112 and 108/110 horizontal bonds. In particular, the fringes around the three overlapping plugs inserted along the bottom of the 109/11 panel, the insert at the top of the 109/11 panel, the 3-4 fringe pattern at the bottom of the 109/5 panel and several other regions containing fringes were photoed **(Fig. 4)**. It is believed that the 3 fringe pattern was due to overheating during the postcure.

The photoelastics of the 103 verticals and 103/101 horizontal were videotaped on April 1, 1997 and viewed by Hugh Evans who reported not seeing more than 1 fringe. The 105 vertical and 105/103 horizontal bonds were inspected by Davis and Andrew on July 5, 1997. Except for the repair area which was photographed there was one region with 3 fringes and the rest contained less than 2 fringes. The 107 vertical and 107/105 horizontal bonds were videoed by Jaret and Chris and viewed by Hugh who reported not more than 2 fringes.

Jaret and Davis examined 109 verticals and 109/107 horizontal bonds on Nov 5, 1997. Several of the T joints had angels with not more than 3 fringes. Two vertical bonds, 109-6/5a and 109-9/13, had large 3' long by 1.5" wide fringe patterns, each containing

about 4 fringes. Several photos were taken and they are on file (**Fig. 5**). It is believed that the stress in these two vertical bonds was caused by overheating during the postcure.

Hardy and Jaret inspected the bonds around the bottom plug, Nov 25, 1997 and found no fringes. (See shift report)

Bond Imperfections.

Allen Inglis, the AV QC inspector, prepared a hand written summary of his inspection of some of the bonds. The ones tabled on June 4, 1996 were

110 verticals	6 pages	12 bonds
108 verticals & 106/108 horizontals	6 pages	complete
106 verticals & 104/106 horizontals	4 pages	6 vert bonds & adjacent hort.

These hand written reports were examined by Brewer, Stachiw, Earle and Evans and a number of features were selected for visual inspection on June 5th by Stachiw, Earle and Evans. These three with Allen leading, inspected selected features. Dave Duff and Art McDonald were also present during part of the time. These reports and the exact features visually examined are on file. Copies of photos of the worst fringes and of examples of the voids, strings and clouds are also available. Only one feature on the 110 row was examined i.e. a group of voids and bubbles at the bottom of the 110-12/2 vertical bond. It was recommended that this be removed before the horizontal bond is poured. Six features on the 108 verticals and 108/106 horizontals were examined. These were white or off-white stringy material and white cloudy material both two and three dimensional with and with out bubbles and voids. Seven features on the 106 verticals and 106/104 horizontals were examined. These were similar to those seen on the other rows. In addition the multiple bubbles distributed around much of the horizontal bond were also examined in a number of critical places were various features had been noticed by others.

Stachiw's recommendations were
- that he saw no bubbles that were large enough to cause a problem. In particular, the 06/104 horizontal bond.
- that all voids (open bubbles) should be sanded out either by hand or with a sander modified to have a small diameter disk.
- that the stringy contamination should be left alone.
- that test blocks should be made to reproduce the white cloudy material and destructively tested.
- that test blocks reproducing the repairs should be made (7 fringes) and destructively tested.
- that the voids and bubbles at the bottom of the 110 vert bond should be repaired.

After vessel completion Allen Inglis prepared a report **"Bond Imperfections and Repaired Areas"** which lists in detail all the imperfections he observed in the vessel bonds over the 2.5 years of construction. This report was prepared from his meticulously kept log books.

Bond Thicknesses:

The bond thicknesses have being measured by the Queen's group and others. Thicknesses below 2.15" were flagged and the length of bonds thinner than 2.15 were noted. In most cases measurements were taken about every 6". These measurements were recorded and are on file. The results can be summarized as follows:

101/102 verticals measured at 0.5' intervals.

F19	102-6/101-6 vert bond	Bottom 3'	2.127" to 2.148"
F11	102-8/101-1 "	Top 2'	2.126" to 2.145"
F14	102-3/101-3	1' from top	2.141"
F15	102-3/101-10	at top	2.131
F3	102-2/101-02	"	2.130
F4	102-10/101-2	"	2.144
F5	102-10/101-5	"	2.100
F6	102-9/101-5	"	2.139
F8	102-5/101-9	"	2.111
F12	102-1/101-1	"	2.128

101/102 & 104 horizontals measured every few inches. Thicknesses every foot were recorded and all thicknesses less than 2.15" were recorded.

11	At 102-8/101-1 top T joint	2.117" to 2.144"	2" long
8	At & right of 104-13/104-6 bottom T joint	2.125" to 2.144"	8" long
13	At 102-1/101-3 top T joint	2.141 to 2.148	2" long
14	Left of 102-3/101-3 top T joint	2.122 to 2.143	2" long
17	At 102-7/101-7 top T joint	2.129"	
18	1' left of 102-6/101-7 top T	2.131"	
2	At 102-2/101-4 top T joint	2.130 to 2.148	4" long
3	At 102-2/101-2 top T joint	2.113" & 2.107"	
4	At & left 102-10/101-2 top T joint	2.106" to 2.148	12" long
8	2" left of 102-5/101-9 top T joint	2.141"	
9	At 102-5/101-8 top T joint	2.148	

104 verticals were measured every 0.5'

E10	104-04/104-03	2.113 to 2.148	along 5' of bond
E11	104-3/104/2 top	2.123	
E12	04-2/104-5	2.149	1' from bottom
E13	104-5/104-1	2.140	3.5' from top
E1	104-1/104-9	2.126	at bottom
E2	104-9/104-11	2.117	at top
		2.130	at bottom
E9	104-4/104-6	2.062 to 2.145	top 0.5'
		2.107"	at bottom
E8	104-6/104-13	2.139" to 2.139"	bottom 1'
E6	104-7/104-8	2.087	at top
		2.146	at bottom
E5	104-7/104-12	**2.033**	at top

104 /106 horizontals. Recorded at least every 1'

12	Right of 104-5/2 top	2.130 to 2.139	along 2' of bond
11	Right of 104-2/3 top	2.098 to 2.133	along 2' of bond
11	Left of 106-5/2 bot	2.047 to 2.116	along 3' of bond
10	Near 104-3/4	2.149	
9	From 104-4/6 to 106-10/1	2.107 to 2.142	along 6' of bond
9	Right of 106-1/10	2.085 to 2.146	along 2' of bond
8	At 104-6/13	2.147	
6	Left of 104-8/7	2.101 to 2.124	along 2' of bond
5	Right of 104-7/12	**2.033 to 2.145**	**along 3' of bond**
2	Right of 104-11/9	2.106 to 2.142	along 2' of bond
1	At 106-8/3 bot	2.115	

106 verticals

D7	OK		
D6	near bottom of 106-13/7	min. 2.104"	along 3" of bond
D5	OK		
D4	near bottom of 106-12/11	min. 2.113"	along 2' of bond
D9	OK		
D8	OK		
D1	near bottom of 106-8/3	min. 2.107"	along 4" of bond
D13	middle of 106-3/4	min. 2.139"	along 3' of bond
D12	106-4/5 not sanded or checked		
D11	OK		
D10	near bottom of 106-2/10	**min. 2.060"**	**along 2' of bond**
D8	near top of 106-1/6	min. 2.098" along 8" of bond	
	3' from top	min. 2.110"	
D9	at top 106-10/1	2.135"	
	at bottom	2.139"	

106/108 horizontals: Not all of this bond was sanded to 600 grit at time of measurements.

11	At 108-11/10 bottom	2.146
10	At 108-10/9	2.104
9	At 108-9/8	2.136
8	At 108-8/6	2.111
	Along 108-6	2.142
	Along 108-1	2.117
2	At 108-4/3	2.144
1	At 108-3/11	2.112

108 verticals

C6	at bottom of 108-5/2	2.144"	
C7	108-5/6 is OK		
C8	near bottom of 108-6/8	min. 2.100"	along 3" of bond
C9	near bottom of 108-8/9	min. 2.132"	along 2" of bond
C10	near bottom of 108-9/10	min. 2.097"	along 2" of bond
C11	ear bottom of 108-10/11	min. 2.135"	along 2" of bond
C1	near top of 108-11/3	min. 2.122"	along 10" of bond
	near bottom of 108-11/3	min. 2.074"	along 2" of bond

C2	at bottom of 108-3/4	min. 2.138"	along 2" of bond
C3	108-4/7 is OK		
C4	108-7/1 is OK		
C5	108-1/2 is OK		
C6	108-2/5 is OK		

108 /110 horizontals. Measurements taken every 1' approximately except where panels thinner.

bottom of 110-10 near 110-10/11	min. 2.131"	along 3" of bond
at bottom of 110-7/slice	2.142"	
along bottom of slice	min. 2.084"	along 1' of bond
bottom of 109-5	min 2.038"	
around repair bottom of 109-11	min. 2.0"	many places around repair
at bottom of 110-4/1 bond	2.144"	
bottom of 110-1	2.144"	
bottom of 110-9	2.148"	
at bottom of 110-9/5	2.147"	
bottom of 110-6	2.105"	

110 verticals. Measurements taken every foot along vertical bonds. Only values below 2.15" are noted.

B3	top 110-4/109-11	2.107"
B4	top, bot. 109-11/5	2.091", 2.131"
B5	top, bot. 109-5/slice	2.122", 2.1"
B6	2' down, bot slice/110-7	2.139", 2.135"
B8	3' down, bot. 110-10/11	min. 2.014" over 1', 2.135
B9	top 110-11/6	2.138"
B10	top 110-6/12	2.12"
B11	top 110-12/2	2.135"
B13	1' above bot 110-13/5	2.148"
B14	top, bottom 110-5/9	2.148", 2.130
B15	top, 2' down, 5' down 110-9/slice	2.135", 2.142", 2.110"
B1	top, 2' down, 5' down slice/110-1	2.135", 2.143", 2.110"

A 2nd set of measurements taken every 6". Values less than 2.15" noted.

B13	Near top 110-13/5	2.149"
B15	Along most of 110-9/slice	Below 2.15" minimum 2.11"
B1	3 spots near bot. slice/110-1	2.143", 2.148", 2.146"
B3	Bot. 110-4/109-11	2.141"
B4	Middle 109-11/5	2.147"

110 /112 horizontals
A number of measurements under 2.15". Smallest measurement was 2.035" which was near the repair (approx. at east).

Chimney Values

Four measurements on each of 7 bonds.
All 28 measurements between 2.392' and 2.582".

103 verticals.

Three to four measurements were made on each vertical bond. Thicknesses less than 2.15" were measured in two places only. The bottom of bonds 103-7/1 and 103-10/13a measured 2.145".

101/103 horizontals.

At least 6 measurements made along the top of each 103 panel. Values less than 2.15" were found along the right hand side of panel 103-12 only. Twenty measurements, every 2.5" along 4' of the bond were less than 2.15". The smallest value measured was 2.109".

105 verticals.

Values less than 2.15" were measured near the top of several bonds
H2 2.132'
H3 2.067"
H4 2.135"
H5 2.091" to 2.098" along 25% of the bond
H7 2.118"
H12 2.119"
The shift report says that the thinnest value was 1.948" but does not say where it was measured. There were several locations around the repair that were less than 2.15", the thinnest was 2.006".

103/105 horizontals.

Of the 76 measurements made around this horizontal bond, 13 were less than 2.15". The thinnest spot was 2.11"

107 verticals.

Except for three locations where surface defects were sanded out all these vertical bonds are thicker than 2.15".
I2 minimum 1.915"
I3 minimum 2.022"
I6 ?

105/107 horizontals.

There was one location near bond I8 which after sanding measured 2.098" and there were four other measurements less than 2.15", the thinnest being 2.114".

109 verticals.

Most of these vertical bonds have thicknesses less than 2.15" at the tops, near the 109/107 horizontal.

J1	2.078"	J2	2.124"	J3	2.076"	J4	2.074"
J5	2.094"	J6	2.020"	J8	2.144"	J9	2.068"
J10	2.029"	J11	2.050"	J14	2.108		

More significantly there is a divot in bond J2 generated by sanding out a crack which developed after postcuring due to a syrup spill. The minimum thickness at the bottom of this divot is 1.77". This is the thinnest spot in the vessel. The cross section of this divot is shown in **Fig. 6.**

107/109 horizontals.

As with the 10 verticals there are many places along this horizontal bond where the bond thickness is less than 2.15". A detailed map of the measurements are on file. Except for a divot above bond J13 all thickness measurements are greater than 2.05". The divot has a minimum thickness of 1.80". One inch away from the minimum the thickness has increased to 1.92" to 2.07".

111 bonds

There are several locations in the 111/109 horizontal bond where thicknesses less than 2.15" were measured. These are between NW and N and also between E and SE. The thinnest value measured was 2.119". The 111/111 horizontal bond was thicker than 2.15".

Bond Widths:

Prior to vessel construction tapered test bonds were made of various widths and destructively tested for strength. It was determined from these tests that the bond gaps should be greater than .064" and less than 0.172" before bonding. The 64th lower limit is an important one because the strength of thinner bonds was found to be inferior. The 172th upper limit was recommended because the probability of bubbles forming due to the exothermic reaction while curing increased with mass of material. On the other hand if no bubbles were observed after construction then the strength was known to be satisfactory. In the field during construction widths less than 64th were avoided but local widths up to 250th were permitted if panel positioning required it. In some cases, since the bonds shrink by about 20% during the curing, the finished product had widths less than 64th. Widths were measured and recorded after postcuring. Exceptions to the specifications are noted below:

101 & 102 verticals
All widths are between 0.088" and 0.17"

101/102 and 104 horizontals.
All widths are between 0.08" and 0.182"

104 verticals.
The top of 104-2/5 and 104-1/9 are wider than 0.200". The later was up to 0.33"

104 & 106 horizontals.
These vary from 0.04" to 0.24". Bonds less than 0.06" were measured above panels 104-5 & 104-1.

106 verticals.
The top of the 106-8/9 vertical bond was measured as 0.04". A number of bonds are wider than 0.200".

106 & 108 horizontals.
Thinnest is two at 0.08. Thickest is two at 0.230"

108 verticals.
Thinnest is one at 0.06" and thickest is one at 0.19"

108 & 110 horizontals.
Thinnest is 0.120" under 110-06. Thickest is 0.340 under 110-01. A number of other thicknesses are above 0.250".

110 verticals
Thinnest bond is 110-5/9 which was .041" to 0.095 "
110-11/6 has widths from 0.075"
110-1/slice had a 0.054" and 110-7/slice had a 0.068".
Thickest 110-4/109-11 had 0.310" at one location and 110-6/12 was at 0.295".

110/112 horizontals.
From 0.227" to 0.315".

Chimney Values.

Four measurements on each of 7 bonds.
Range of 28 values was 0.097" to 0.175"

103 verticals.
Three measurements were made along each vertical bond. The range of values was 0.096" (at bottom of 103-1/9) to 0.224" (at top of 103-07/1).

101/103 horizontals.
Up to six measurements were made along the top of each 103 panel. Values were normal from 0.092" at the top of 103-3 to 0.220" at the top of panels 103-12 and 103-2, except at the top of 103-6 where a value of 0.058" was measured.

105 verticals

Measurements of the width of these bonds varied from 0.098" to 0.225"

103/105 horizontals

As with the 105 verticals this horizontal bond was within specifications. The thicknesses measured varied form 0.099" to 0.221"

107 verticals

As with the row above the bond widths were within the specifications and varied from 0.080" to 0.220".

105/107 horizontals

The measured width of this horizontal bond varied from a minimum of 0.077" to a maximum of 0.214"

109 verticals

Width measurements varied from 0.084" to 0.180".

107/109 horizontals

Measurements varied from 0.070" to 0.198".

111 bonds

The width of the finished bonds on the bottom plug were all on the low side of the specifications. The gap was smallest on the inside of the vessel and ranged from 0.065" to 0.120". The gap range from outside measurements was from 0.068" to 0.140".

Vessel Deflection with Chimney Weight

The deflection of the upper vessel due to the additional weight of the chimney was measured by Rob Komar in Nov 1996. His email report on his measurements follows. The four positions on the collar were approximately equally distributed NE, NW, SE & SW. The panel positions were not as equally distributed around the circumference, three adjacent panels in the E sector were missed, a N and a NE panel were also missed.

The following is a table of the dial gauge readings taken at three times: when the chimney was initially raised, when the chimney's weight was fully on the collar, and when the chimney was raised again shortly after. The last column is the deflection (in thousands of an inch) at each dial gauge location. The number following the panel number in the bottom half of the table is the distance (in inches) between the dial gauge and the collar.

Dial Gauge Location	Chimney Position			Deflection
	Raised	Lowered	Raised	
On collar				
110-06	34	74	34	40
110-05	35	74	34	40
110-04	86	30	87	43
09 slice	1	42	1	41
On 110 panels				
110-06 (12.5")	65	87	64	19
110-12 (17")	51	70	51	19
110-02 (13")	54	77	54	23
110-05 (13")	3	23	3	20
05 slice (17")	36	56	36	20
110-04 (19.5")	-	1	79	22
109-11 (16")	48	66	47	19
110-10 (12")	56	78	55	23

The average deflection of the collar was 41th., and the average deflection of the 110 panels was 21th. (at an average distance of 15" from the collar).

Location of NCD Attachment Anchors

The NCD anchors were bonded onto the vessel with PS-30 during the construction of the lower hemisphere and the locations measured with the theolodites during the positioning of the panels. Each anchor was subjected to a pull test before acceptance. The coordinates of these anchors has been reported by **R. Komar and P. Doe. See SNO-STR-97-045.**

Vessel Shape

The vessel shape was measured in two stages. The upper hemisphere was surveyed late 1996 and the lower half in late 1997. The results are contained in two reports by **Rob Komar, SNO-STR-97-053 and SNO-STR-98-003**. Quoting from these reports.

" The average spherical radius was seen to be close to 236.38". The deviations from sphericity in the lower half were at most ±0.30" and are likely to be less at the completion of the vessel."

While the upper hemisphere was hung on the ropes its elliptical distortion was ±0.54" at the equator but this had to be (and was) reduced as the lower hemisphere was constructed e.g. it was reduced to ±0.43" after the 103 row was completed. The design specifications was ±0.5".