Magnetic Field Compensation for the SNO Detector

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Magnetic field compensation for the detector cavity is provided to cancel the earth's field at all photomultiplier locations. The system is designed to cancel the earth's field to about 10% of its usual strength.

The uncompensated earth's field is approximately 0.6 Gauss. The field in the cavity can be conveniently decomposed into two components – a vertical component (about 0.5 Gauss) and a horizontal one (about 0.3 Gauss). The vertical earth field component is to be cancelled by a set of "transverse" coils (i.e. wound in horizontal planes around the SNO cavity). The horizontal earth field component is to be cancelled by a set of "longitudinal" coils (i.e. wound in vertical planes). The various coil sets are discussed in more detail below.

Some important engineering design considerations are:

1. Total power consumption

   The coils will be operating almost continuously for more than 10 years. Hence any savings (through design innovations) in the power dissipated by the coils has to be factored into the total cost for the compensation system. Also one has to consider the power saved by the cooling system to take heat away and the efficiency of the DC power supplies.

   An example of the cost difference between using a single thick wire and many thin wires to make the coils is given in Appendix A.

   There may also be some total (capital plus operating) cost advantage in using closely spaced coils as oposed to wider separated coils since closed spaced coils would require less current and hence use less electricity.

2. Power Supplies

   We would like to keep the number of supplies required to a manageable number. Also, the power supplies do not have to have very low ripple but should be as efficient (more than 50%) as possible.

3. Heating of the Wire

   The wires are to buried in concrete and the heat generated by the wires will flow towards the water. The temperature rise in the wires (which will be bundled together) is an important factor to consider. This could place constraints on the size and number of wires which can be bundled together. Some experience with this question could be found in design of electrical de-icing cables which are buried in concrete garage ramps, etc.

4. Splicing Wires

   Special attention should be given to how the wires are to be spliced and taped up especially for any splice buried in the concrete. Bad splicing/taping will probably be the largest contributor to coil failure. Buried splices should withstand thermal cycling and the tape should not corrode in concrete. Splices which are not buried in concrete should be located in an accessible location.

Computer Calculations

Two computer programs have been written for the magnetic compensation coil design — one for the "transverse" and one for the "longitudinal" coils. Each loop is divided into short (~30 cm) straight approximating line segments and a subroutine is used to calculate the magnetic field at a PMT position from that line segment. The magnetic field contributions from all the segments forming the loops are added to get the total field at the PMT position due to either the "transverse" or the "longitudinal" coils. Each program stores the results in a computer file (one for the "transverse" and one for the "longitudinal" coil). Finally another computer program is used to add the two files together to obtain the final field at the PMT positions.

A couple of ancilliary programs are first used to find the optimum current through the loops for a few hundred PMT positions. The optimized currents are then used to calculate the "transverse" or the "longitudinal" field at 1850 PMT positions (approximately 0.5 meters apart). The "transverse" or "longituidinal" calcaulation each require 3 hours on the MicroVax computer.

Several approximations have been used in the field calculations. The loops for the "transverse" coils have been treated as exact circular loops which are spaced equidistant from their neighbours. In practice there will be some sag to the loops and some deviation from circularity. Where the "longitudinal" loops run along a sloping surface, they have been approximated as a straight line (in reality it is a small parabolic curve). The effect of residual magnetization of the deck structure and steel liner has not been included in the calculations.

Two versions of cancellation coils were calculated. One version involves loop separations which are relatively "tight" (0.4 to 0.7 meters) and the other with "loose" separation (0.8 to 1.5 meters). For the "tight" version the final magnetic field at the PMT position is smooth to a maximum "residue" of 8.1% in the vertical component and to a maximum "residue" of 7.1% in the horizontal component. For the "loose" version the final magnetic field at the PMT positions is smooth to a maximum "residue" of 12.7% in the vertical component and to a maximum "residue" of 13.2% in the horizontal component. ("Residue" is defined as follows: Say the earth's vertical field is 15 (arbitrary) units. Then saying the "transverse" coil set will cancel these 15 units with a maximum "residue" of 8% means that at a very small number of PMT positions anywhere from $\pm(15 \times 8\%) = -1.2$ to $+1.2$ units of residual field in the vertical direction will remain.)

For the actual coils, the "residue" will be somewhat higher than the computer calculated numbers because of the simplifying assumptions we have put in.

The "Transverse" Coils

In the "tight" version the "transverse" coils consist of 53 circular loops arranged in 6 sets (A to F, see Figure 1). The spacings between loops is not the same from set to set. The loops are tied onto the rock bolt and screen before the infill concrete is poured.

Each loop is composed of twenty turns of say #15 gauge wire connected in series to give a loop resistance of about 13 ohms each. A number of loops would be wired in series to one power supply. The number of power supplies has to be decided.

The details of the "tight" "transverse" set are given in Table 1a. Table 1b lists the details of the "loose" set of "transverse" loops. Further optimization may show that each set listed below may have to be subdivided into more different current carrying loops.

Table 1a Details of the "tight" Transverse Loops

Set	Spacing** (meters)	Number of loops	Circumference of a loop (meters)	Amp-turns	Current for 20 #15 wires (amps)	Resistance of one loop (ohm)
A	0.53	8	~59	38.4	~1.9	~13.0
B	0.53	9	~65	20.0	~1.0	~13.0
C	0.40	10	~68	19.1	~1.0	~13.5
D	0.40	9	~68	26.5	~1.3	~14.0
E	0.45	11	~62	20.0	~1.0	~12.8
F	0.68	6	~47	42.3	~2.1	~9.8

** As measured along the stainless steel sloping surface

Table 1b Details of the "loose" Transverse Loops

	Amp-turns	Current for 20 #15 wires (amps)
A	38.4	~1.9
B	82.8	~4.1
C	40.0	~2.0
D	56.5	~2.8
E	38.0	~1.9
F	100.3	~5.0

The spacing for the "loose" loops is twice that in Table 1a.

The "Longitudinal" Coils

In the "tight" version the "longitudinal" coils consists of 58 loops arranged in 3 sets (A, B and C, see Figure 2a). Typical cross sections of the loops are shown in Figure 2b. Note the loops run under the steel deck of the detector. The spacing between loops is not the same from set to set. The wire used is the same as for the "transverse" loops (a bundle of twenty #15 wire).

The details of the "tight" "longitudinal" set are given in Table 2a. Table 2b lists the details of the "loose" set of "longitudinal" set of loops.

Table 2a Details of the "tight" Longitudinal Loops

Set	** Spacing (meters)	No. of loops	Circumference of ~~one~~ a loop meters	Amp-turns	Current for 20 #15 wires amps	Resistance of ~~one~~ a loop ohm
A	0.3	38	78 to 86	12.1	~0.6	~17.0
B	0.4	14	60 to 75	18.9	~1.0	~14.0
C	0.5	6	33 to 48	39.3	~2.0	~8.4

** As measured along the stainless steel sloping surface

Table 2b Details of the "loose" Longitudinal Loops

	Amp-turns	Current for 20 #15 wires (amps)
A	25.8	1.3
B	45.5	2.3
C	84.4	4.2

The spacing for the "loose" loops is twice that listed in Table 2b.

Although the installation and material costs of the "loose" set of cancellation coils is lower, more current is used so that after 10 years of operation the total (capital and operating) cost could be higher.

Appendix A

Consider a circular current loop 11 meter in radius (69.1 meters circumference) and carrying 25 Amp-turns. We calculate how much copper and how much power is needed if the current loop was made out of 20 turns of #15 (thin) wire or one turn of #10 (thick) wire.

Data:

#15 wire: 10.45 ohm/km, 9.86 lb per 1000 feet

#10 wire: 3.28 ohm/km, 31.43 lb per 1000 feet

Table A Comparison of Thin and Thick Wire Current Loop

	I Amp	V Volt	R Ohm	Power Watts	Wt. Cu lb.	Cu Cost	Elect. Cost	Total Cost
twenty #15	1.25	18.1	14.44	22.6	44.7	$313	$197	$510
one #10	25.0	5.7	0.23	141.3	7.1	$50	$1186	$1236

Electrical costs are based on 10 cents per kW-hour and does not include the efficiency of the power supplies. Although the cost of copper is higher for the bundle of thin #15 wires, their power consumption is much lower than the thick #10 wire and after ten years the electrical costs saved is substantial.

A power supply that runs at 18 volts and 1.25 Amps is more efficient and easier to make than one at 5.7 volts and 25 Amps. The efficiency of the power supplies and the cost for removing the heat generated by the coils has not been factored into the above "Total Cost".

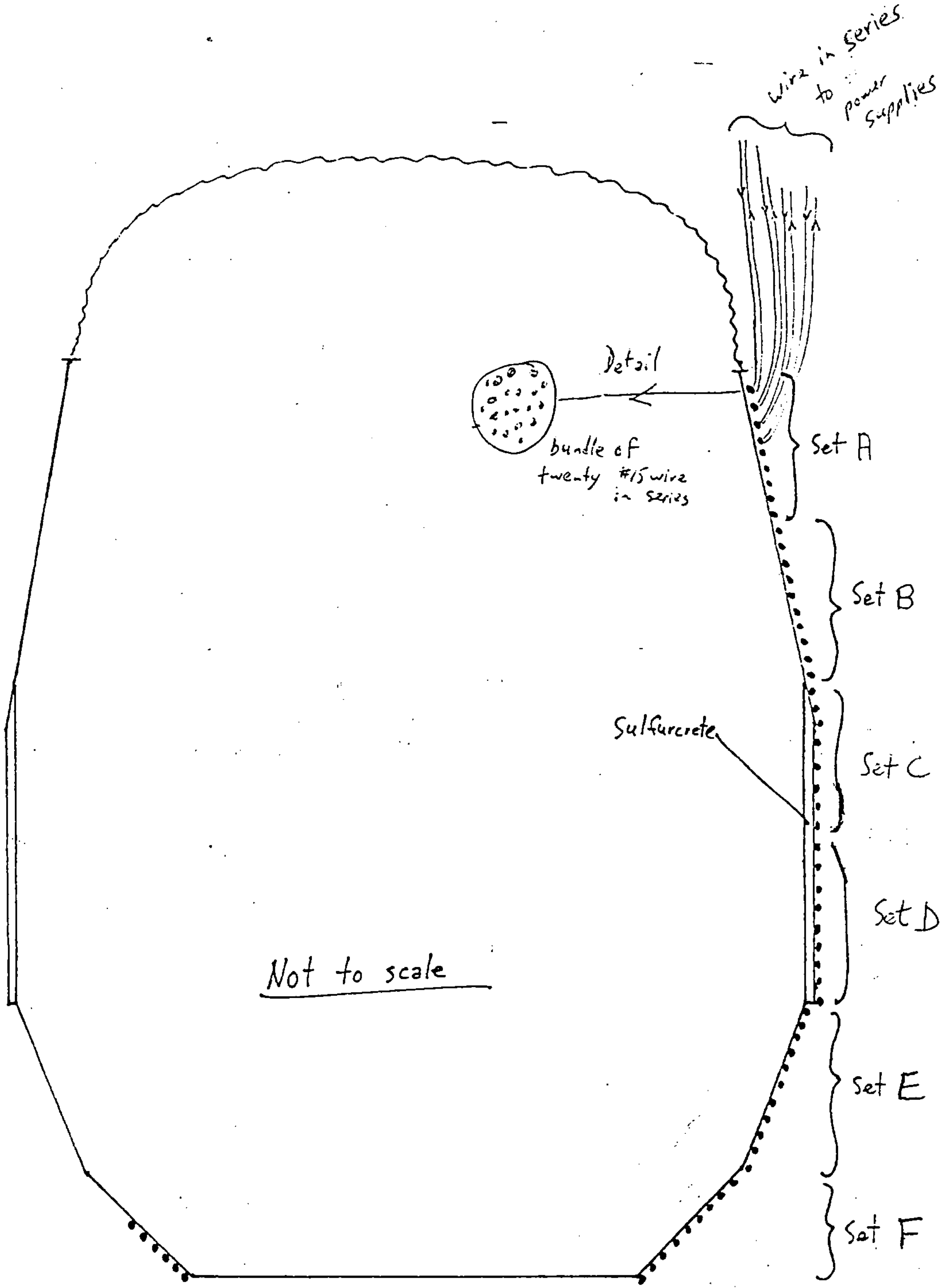

Figure 1 "TRANSVERSE" COILS

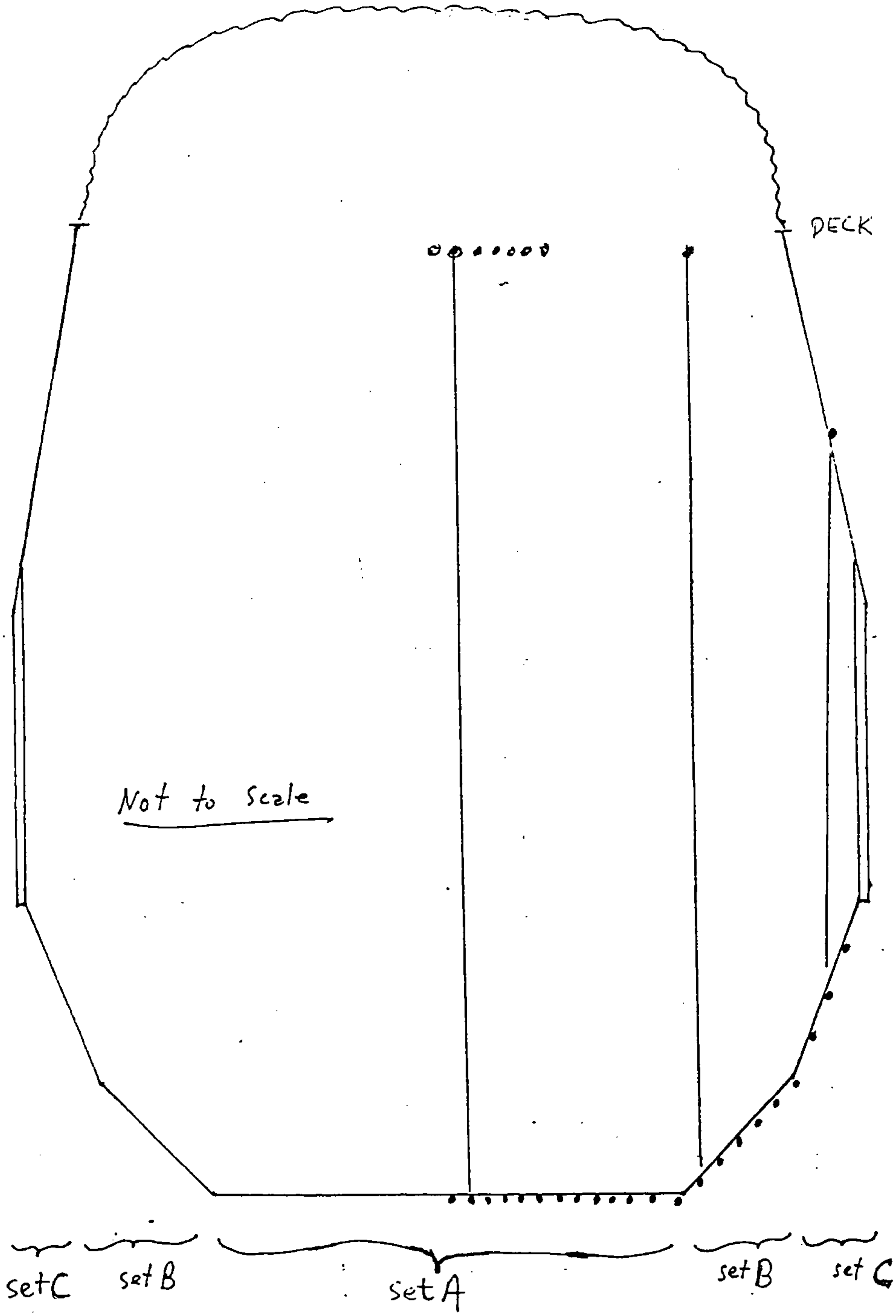

Figure 2a "Longitudinal" Coils

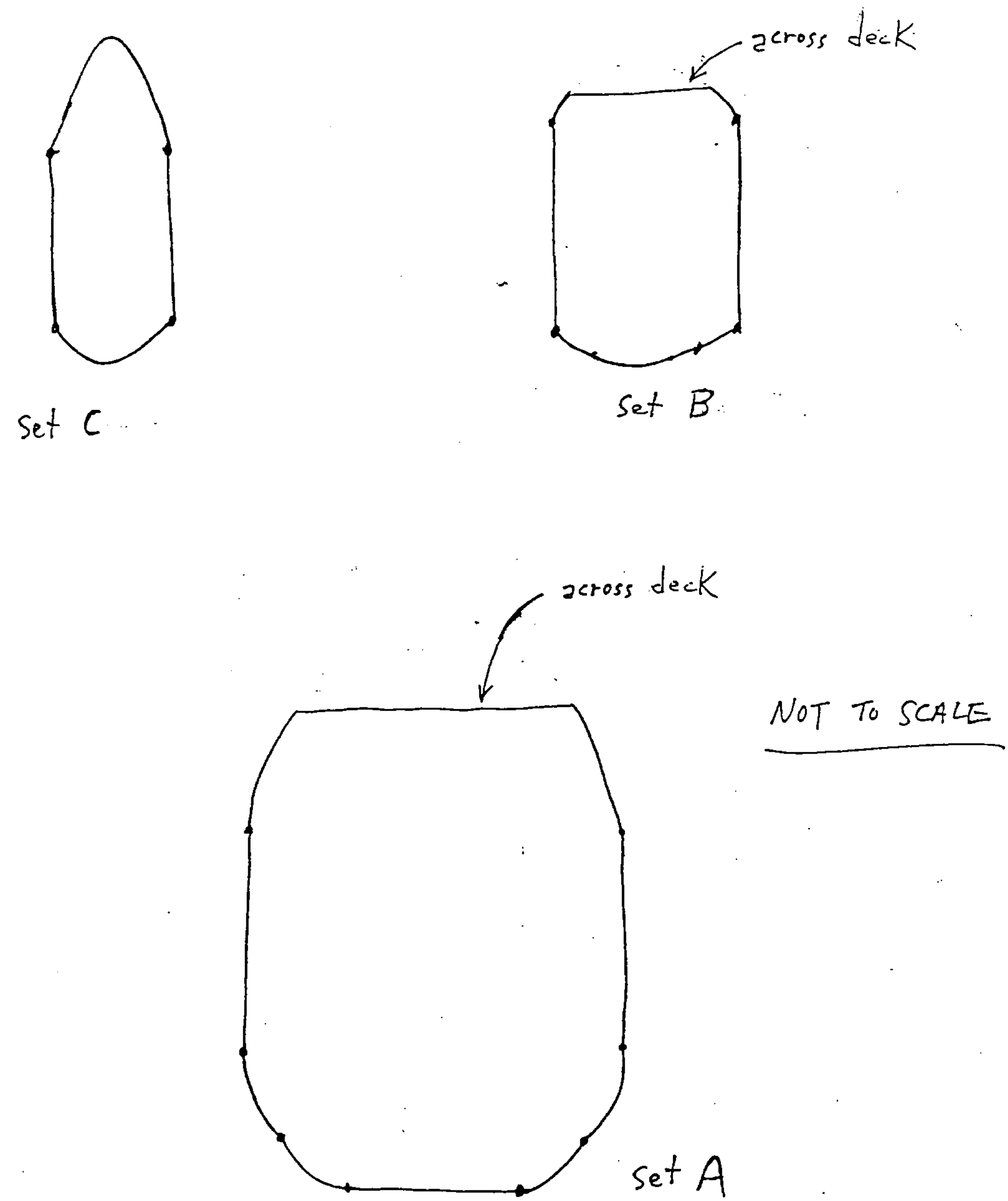

Figure 2b Typical cross sections of "Longitudinal" Coils

Magnetic Field Compensation Update

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Several more "loop" spacings have been run since the SNO-STR-90-82 report on magnetic field compensation. The results are as follows:

Transverse Coils (cancels the z (vertical) earth field)

No. Loops	Residual (%)
53	9.1
~27	12.7
~14	12.9
6	14.9
5	18.3

Longitudinal Coils (cancels the x (horizontal) earth field)

58	6.1
~29	8.6
~15	8.7
8	16.2
6	20.9

The term "residual" is defined in SNO-STR-90-82.

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