SNO-STR-91-5

To: The SNO Collaboration

From: Coil Task Force

Date: Feb. 13, 1991

Re: **Cancellation of the Earth's Magnetic Field**

1 Introduction

It is proposed that the effect of the earth's magnetic field on the PMTs be reduced by constructing a set of current carrying coils to cancel the earth's field. The earth's magnetic field in the Sudbury region is about 5.7×10^{-5} Tesla, a combination of 5.5×10^{-5} Tesla along the vertical direction and 1.5×10^{-5} Tesla along the horizontal direction (Hallman and Cluff, SNO-STR-90-101). The criteria used in setting the cancellation coil specifications are outlined in Section 2. Section 3 describes the calculations that were performed, the results and the conclusions. The specifications for the cancellation coils are contained in Section 4.

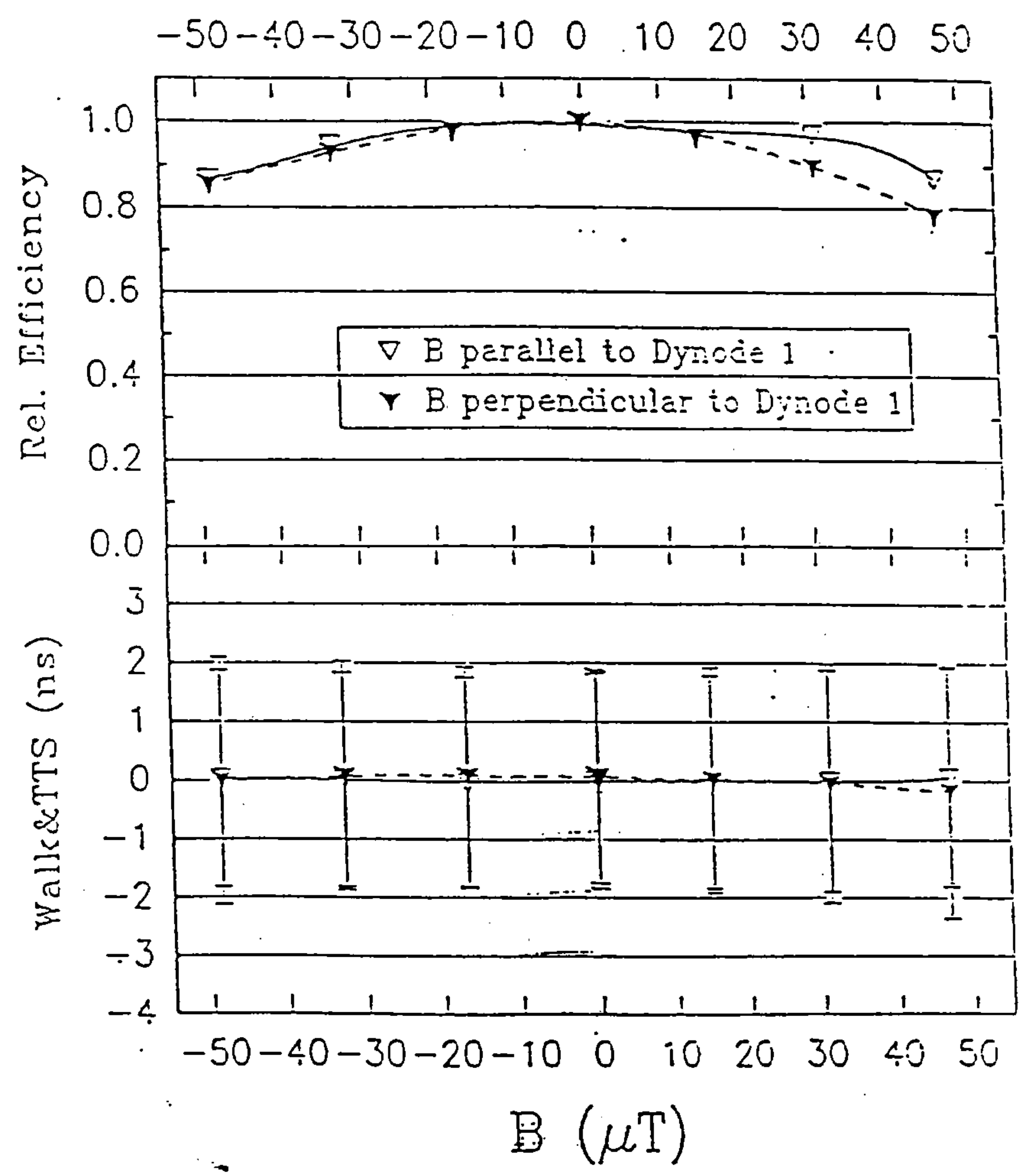
2 Design Criteria

1. The magnetic field at any PMT location is to be reduced to 30% of the earth's value, i.e. $B_{PMT} < 30\% \times 5.7 \times 10^{-5} = 1.7 \times 10^{-5}$ Tesla.

   This criteria results from performance measurements on the Hamamatsu R1408 (20 cm) PMTs (R. MacLeod, M.Sc. thesis, Queen's University). Figure 1 shows the PMT single photoelectron efficiency and timing resolution as a function of a magnetic field perpendicular to the PMT's axis. At 30% of the earth's field ($30\% \times 57 = 17$ μTesla) the decrease in detection efficiency is 4% while at the full earth field it is 10%. Figure 2 is a simulation of the photoelectron trajectories for full photocathode lumination. It shows that if there is no external magnetic field, 96% of all photoelectrons will strike the dynode opening. With 1.6 $\times 10^{-5}$ and 4.0 $\times 10^{-5}$ Tesla fields perpendicular to the PMT axis, the fraction decreases to 92% and 88% respectively; corresponding to losses of 4% and 8% in detection efficiency (relative to the zero field detection efficiency). This is consistent with data obtained at Queen's University. The same figure also shows that a magnetic field up to 4 $\times 10^{-5}$ Tesla along the PMT

Hamamatsu 20cm DIAM

R1408 #ZW262



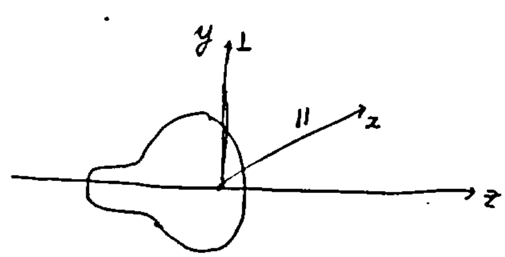
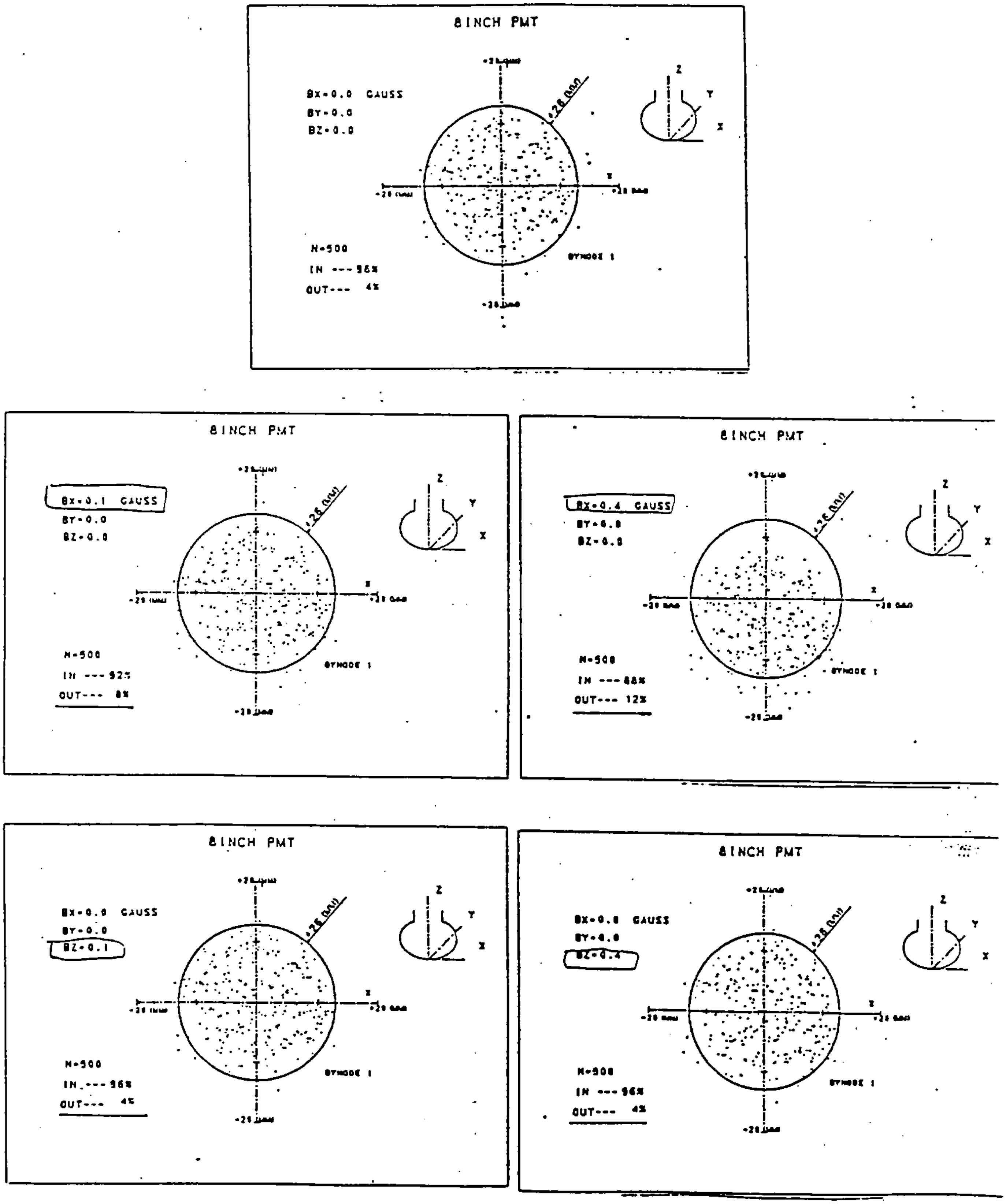


Figure 1 Effect of Magnetic Field

Figure 2 Simulation of Electrons on First Dynode

R1408 (K-DY_1=570V)



axis has no effect on the photoelectron detection efficiency.

2. Each coil will consist of at least 20 turns with all electrical connections between the turns to be accessible above the deck. This will allow reconnection of individual turns should a number of turns become shorted or open circuit.

   In the extremely unlikely case that one coil is completely destroyed, the maximum total field at the PMT locations will not exceed 2.4×10^{-5} Tesla, so only a small number of PMTs will suffer a few percent loss in single photoelectron detection efficiency and timing resolution.

3 Computer Calculations

The vertical component of the earth's field is to be cancelled by using coils in horizontal planes (i.e. horizontal coils). The effect of the mild steel deck on the magnetic field created by these coils has been studied. It was concluded (SNO-STR-90-168) that the deck modifies such a field to a distance of six meters and that the effect actually made the vertical cancellation field at these positions more uniform. It was also clear that the mild steel deck would drastically distort the magnetic field of any current carrying coil which runs through the deck. Hence we concentrated calculations on the horizontal coils only.

In SNO-STR-91-1 computer calculations were presented for a configuration of horizontal coils situated along the walls of the cavity. It was concluded that the limiting factor in the design was the diverging field (especially in the horizontal direction) at the PMT positions near the bottom of the geodesic support.

Another set of calculations have been done to examine the effect of placing two coils beneath the floor of the stainless steel liner and ten coils along the wall of the cavity. The coils in the floor would reduce the divergence of the field. The geometry used for these computer calculations is given in Figure 3.

Figure 4 shows the cancellation field produced by the configuration of twelve coils. The distance along the PMT geodesic, starting from the top and heading towards the bottom, is normalized to one. The peak-to-peak fluctuation in the y (vertical) cancellation field is 0.38×10^{-5} Tesla and the maximum residual in the x (horizontal) direction is now only 0.13×10^{-5} Tesla. This is a substantial improvement in the residual x field compared to the case where the coils are only along the wall (0.7×10^{-5} Tesla).

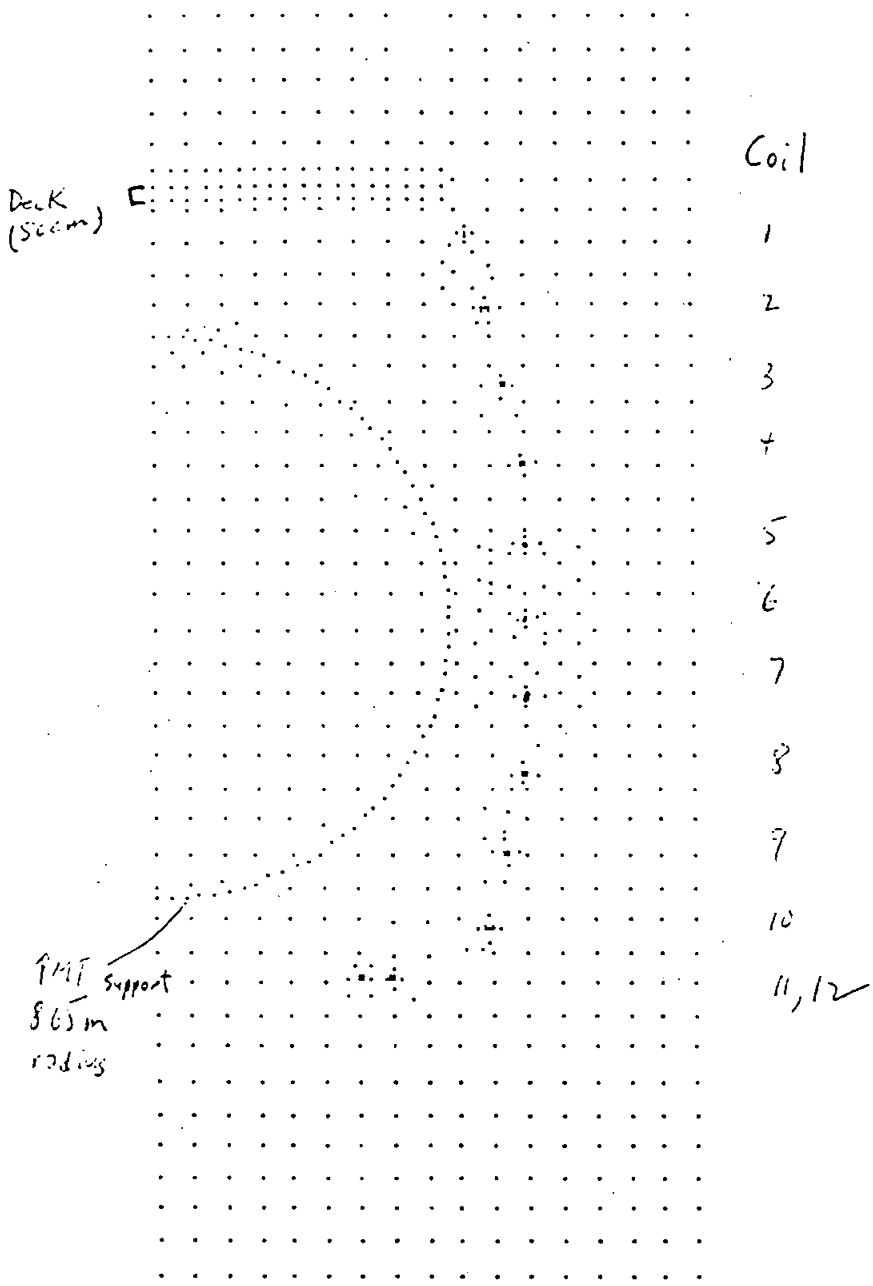
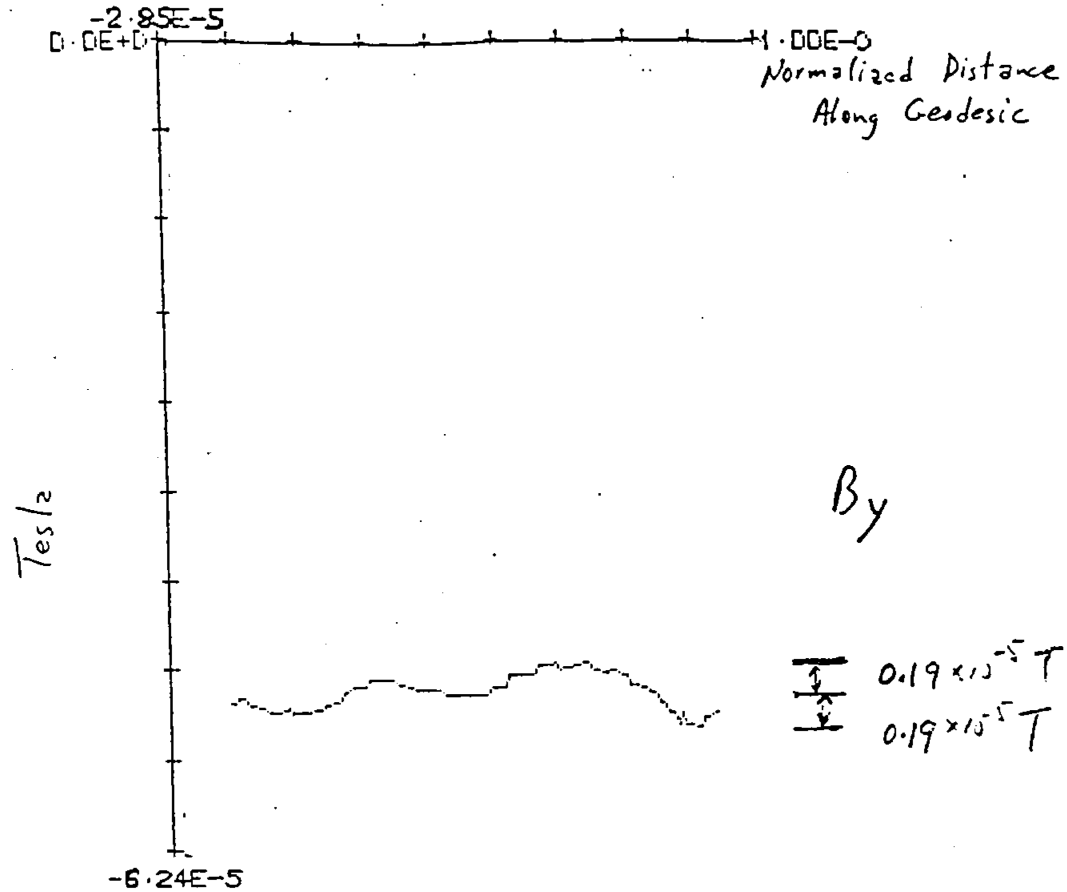


Figure 3 12 Coil Geometry



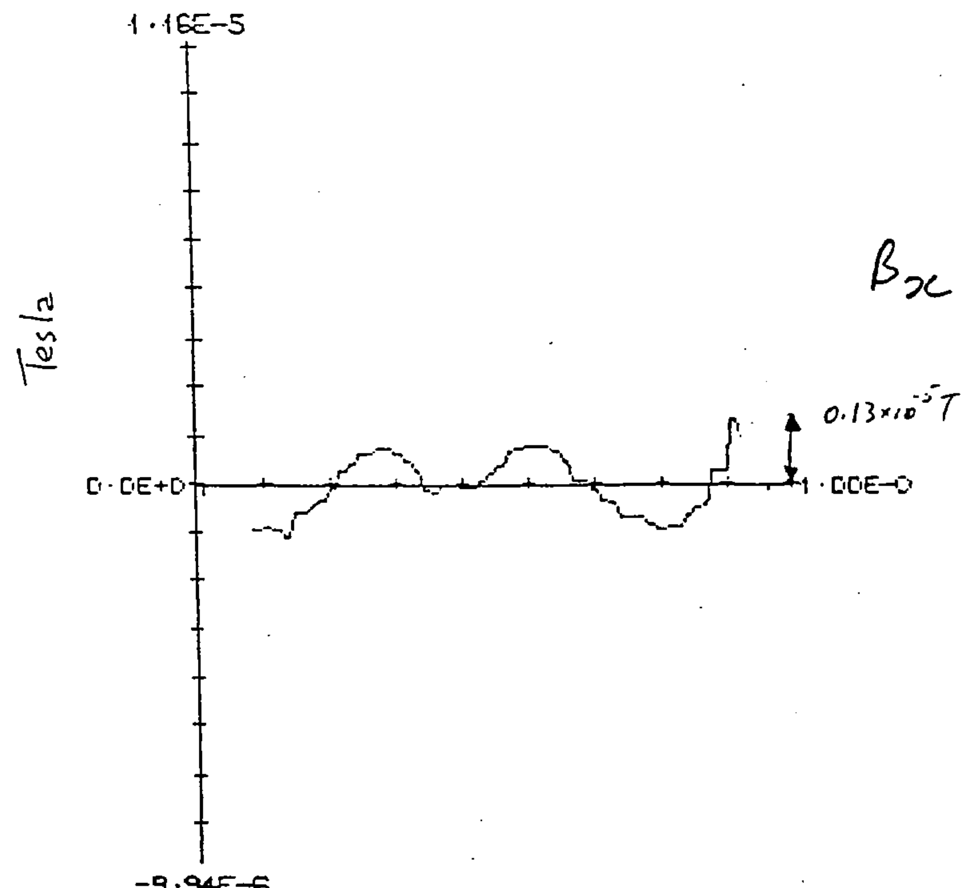
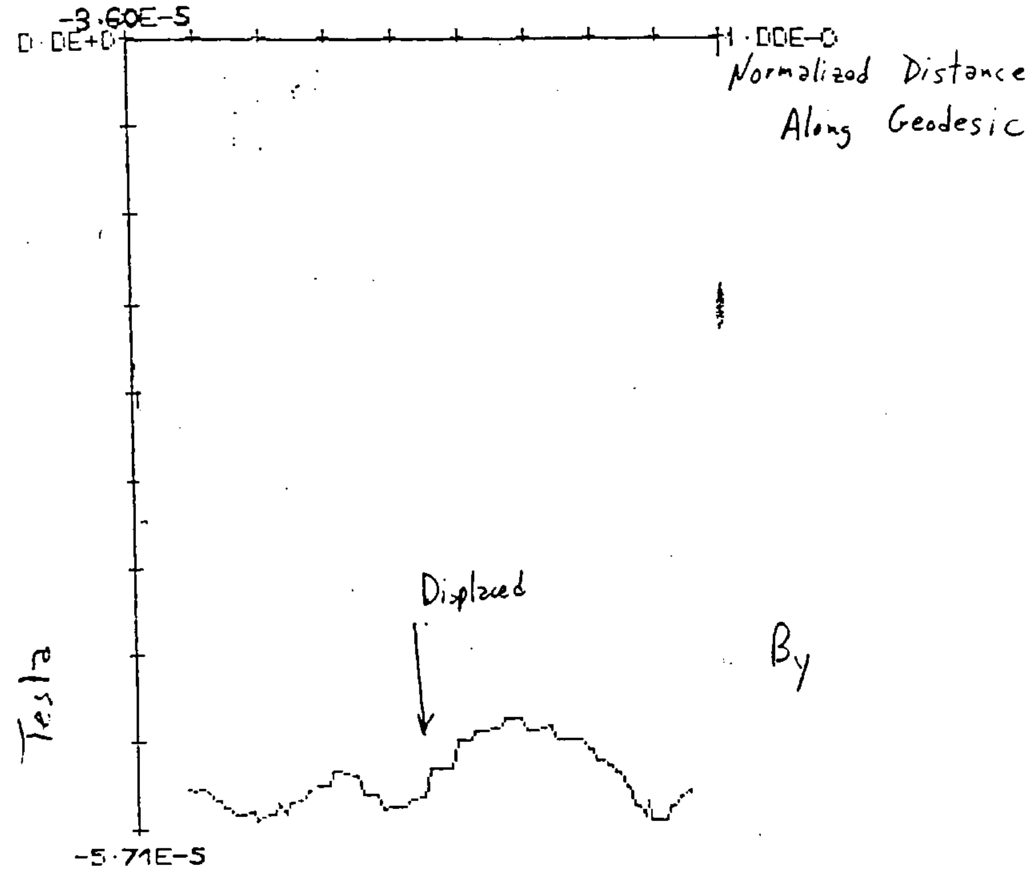


Figure 4 12 Coils.



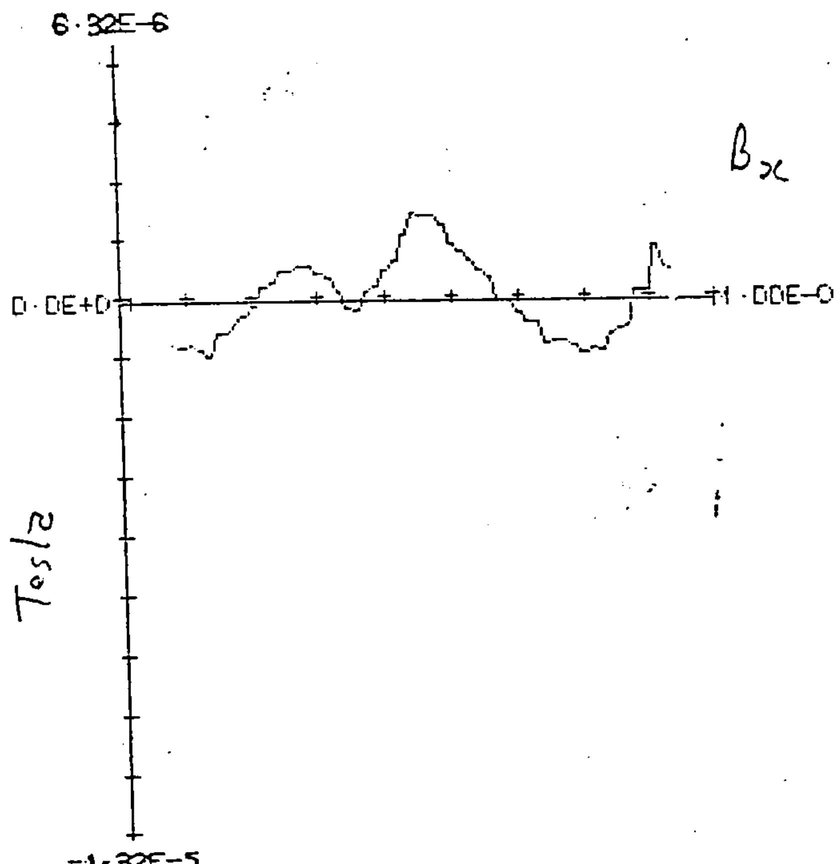


Figure 5 Center Coil Displaced 20 cm

The maximum total residual field (at a few PMT positions only) is

$B_z = 0.19 \times 10^{-5}$ Tesla

$B_x = (1.5 + 0.13) \times 10^{-5}$ Tesla

$B_{net} = 1.64 \times 10^{-5}$ Tesla which just satisfies the design criteria.

The effect of misplacing the coil located at the mid-plane of the cavity (and nearest to the PMTs) by 20 cm is shown in Figure 5. The increase in B_x compared to Figure 4 can be compensated for by adjusting the currents in the misplaced coil and the two coils adjacent.

The effect of a small radial distortion in one coil (and no other coils switched on) has been calculated. For a 60 cm length of a coil which finds itself 10 cm closer to the center, there is a 1.6% change in the horizontal field and a 0.8% change in the vertical field for the PMT closest to the distortion. Therefore we specify that the coils should not be out of round by more than 10 cm. The engineers say this is easily achievable.

The deck geometry for the computer calculations has been modelled as a 50 cm thick slab and the magnetization of mild steel scaled by $50/2.5 = 20$ to give it an effective 2.5 cm thickness of mild steel. A calculation was run for a deck geometry 300 cm thick with a magnetization of 2.5/300 to determine the effect of an extended, weak deck/truss structure on the cancellation field. There was no difference when compared to the 50 cm thick slab results.

The effect of the deck and trusses on the earth's magnetic field extends to about one deck/truss thickness (Hallman and Cluff, SNO-STR-90-167) which is approximately three meters.

Summary

The twelve coil configuration gives satisfactory cancellation in the vertical direction and does not create a large horizontal component. For a small number of PMTs the resulting net field will be close to the maximum tolerable field. The effect of coil misplacement and out of roundness has been calculated for two special cases and the effect is not large.

4 Cancellation Coil Specifications

The Coils Required

Coils to cancel the horizontal component of the earth's magnetic field are not required in the SNO detector.

Coils are required in the SNO detector to cancel the vertical component of the earth's magnetic field. These (horizontal) coils are to be installed in horizontal planes. The coils will be located between the insulation and the shotcrete.

There is to be a total of twelve coils. Two of these are underneath the floor. The specified elevations with reference to the center of the PMT support structure and radii are given in Table 1 and shown in Figure 6.

Table 1 Elevations and Radii of the Horizontal Coils

Coil No.	Elevation* (meters)	Radius (meters)
1	12.0	9.3
2	9.6	9.8
3	7.2	10.3
4	4.8	10.9
5	2.4	11.0
6	0.0	11.0
7	-2.4	11.0
8	-4.8	10.9
9	-7.2	10.3
10	-9.6	9.8
11	-11.0	7.0
12	-11.0	6.0

* As measured vertically from the center of the PMT support structure.

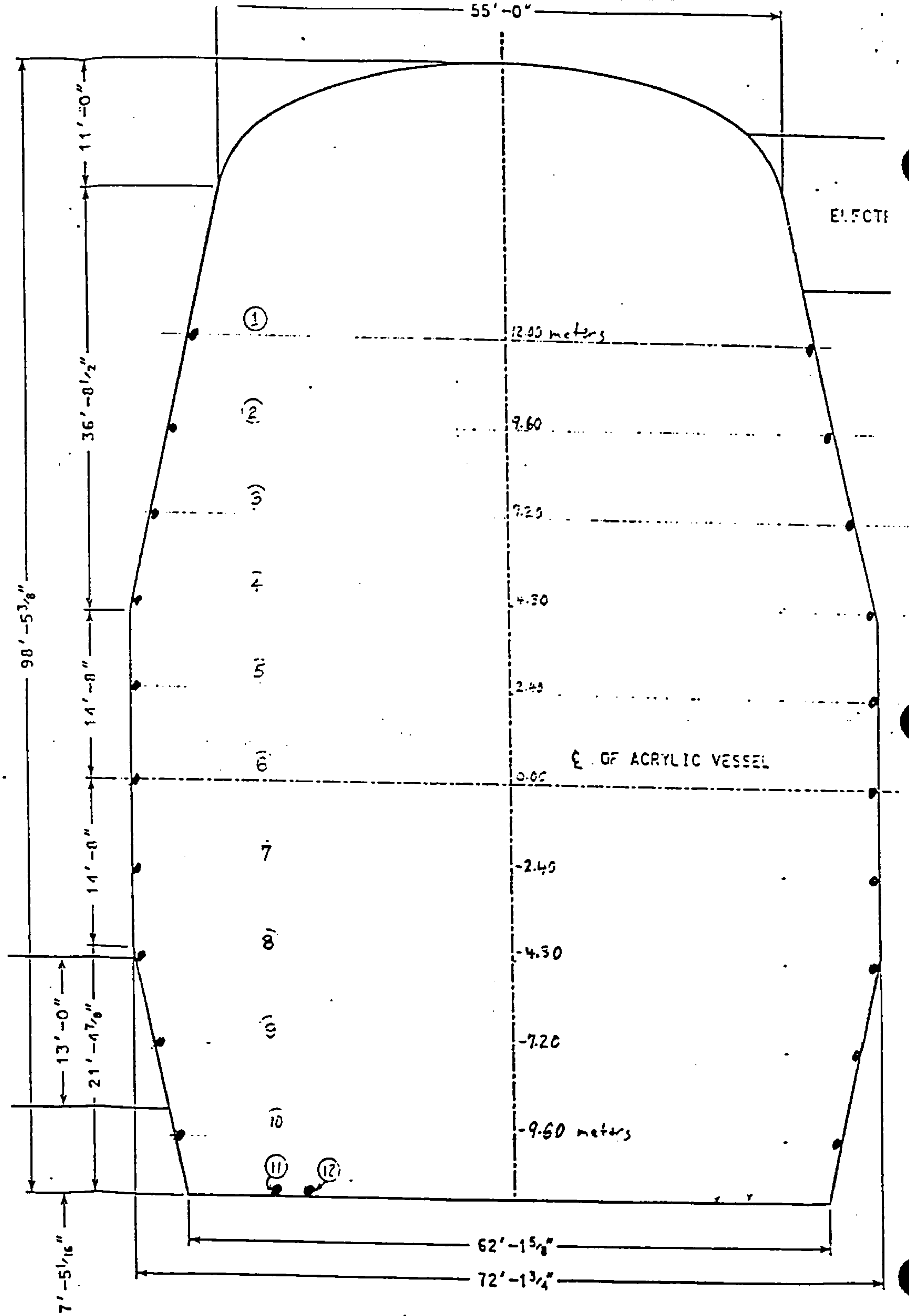


Figure 6 Elevations of Coils

Amp-turns in each Coil

In normal operation, all twelve coils will be energized. The amp-turns in each are approximately that listed in Table 2. Each coil will consist of at least 20 wires and the ends of each wire must be accessible at the top of the deck.

In the very unlikely event of the destruction of a coil, we would change the currents in the adjacent coils to partially compensate for the loss. Then the amp-turn required in this case is about **twice** that listed in Table 2. This represents the maximum amp-turn that a coil would have to carry and hence the current rating of the wire and number of turns in the coils has to be designed to be able to accomodate this pathalogical case.

Table 2 Amp-turns for all 12 coils in Operation

Coil No.	Approx. Amp-turns**
1	478
2	281
3	268
4	236
5	236
6	236
7	236
8	236
9	272
10	389
11	165
12	165

** Multiply by about a factor of two for the worse case.

The gauge of wire to be used and the number of turns in each coil is to be optimized by Monenco. The optimization is to include such factors as cost of the wire, installation cost and total power consumed over 15 years of continuous operation. The final gauge and number is to be approved by the SNO Institute and Monenco.

Coil Installation

(a) Placement of the Coils

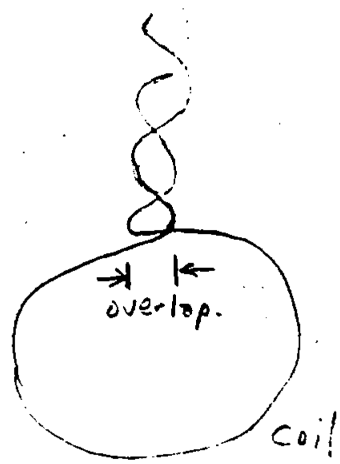
No section of a horizontal coil shall be more than ±10 cm from that listed in Table 1.

(b) Radial Distortion of the Horizontal Coils

The horizontal coils shall not deviate more than ±10 cm from the radius of a true circle as listed in Table 1.

(c) Wiring Running between the Coil and the Deck

The coil will form one complete circle in the horizontal plane with an overlap less than 10 cm. For each coil, the cable running down and the cable running up shall be twisted together with one turn per meter.



The cables running up and down are not to run through the interior of any of the circles that the coils form. The cables for all twelve coils can come up the same side of the cavity.

The conduit for the coils and the fasteners shall be made from a non-magnetic material.

Power Supplies

(a) There shall be one power supply per coil.

(b) The current from each power supply shall be adjustable.

(c) The power supplies shall run from 120 VAC.

(d) The efficiency of the power supplies shall be greater than 90%.

(e) Switching-type power supplies shall not be used.

(f) The peak-to-peak ripple of the power supply output shall be less than 2%.

(f) There shall be the minimum of spikes and transient noise from the power supplies.

(g) The power supplies are to be located in the electronics corridor and away from the detector electronics and detector cabling.

Residual Magnetization on the Deck Steel

No specification will be set on the residual magnetization of the mild steel in the deck and trusses from the supplier. This is because the final residual magnetization of the deck and trusses will be dependent on the history of welding, drilling, riveting, etc. that occurs in the construction. It is anticipated that selective degausing of parts of the deck and trusses or other mitigative measures (such as placing small permanent magnets in selected places) will be carried out as deemed necessary.