Detailed Cavity Background Evaluation

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SNO-STR-90-102

September 7, 1990

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Cavity Specifications

The document specifying requirements of the cavity and shielding in terms of background limitations has been completed [1]. A limit to the allowable stainless steel U/Th contamination in the waist section was set at 30 ppm. Similarly a maximum allowable U/Th contamination level in the deck of 3 parts per thousand was fixed. It was also determined that the effective liner thickness could be doubled with only a 0.5% increase in overall γ-ray background for the liner further than 2 meters along above the top of the waist section and further than 4 meters along below the bottom of the waist section. For further details see the specification document.

As this work was carried out it became clear that several minor modifications to the shielding were desirable. These are discussed below.

Geometry Alterations

In the original INCO cavity drawings the liner reached a diameter of 22 m at the outer edges of the waist section. In the Monenco drawings the liner was to meet the *inner* edge of the shield which is 25 cm closer to the acrylic vessel. This resulted in an approximate doubling of the background from the non-waist liner. (Estimated backgrounds reaching the acrylic vessel are indicated in Table 1. The column for backgrounds with the original barrel shape drawn up by INCO is labelled "INCO". Backgrounds with the subsequent Monenco shape are given in the column labelled "Monenco".) Most of this background increase can be removed by extending both the top and bottom of the waist section by 1'6". This is shown in the column labelled "extended" in Table 1.

An additional change in the cavity shape is being considered for engineering reasons. This would involve leaving the cavity diameter at approximately 22 m below the waist section. The background consequences of such a change is indicated in the column labelled "jug". It results in the lowest background of all the configurations considered.

Backfill

Detailed estimates of the effect of concrete backfill have been made. If the backfill does not contain boron, the background from the liner next to the backfill is systematically *increased* (by up to a factor of 2.4 for a concrete thickness of 4") by the thermalizing effect of the concrete. For a 4" backfill thickness, this would result in an overall external background increase of 9% over the "extended" case. If 0.5% boron is added to the backfill there is instead a decrease of at least a factor of 2.7 for backfill thicknesses greater than 2". This would reduce the overall external background to 7% less than the "external" case. It is therefore recommended that 0.5% boron be added to the shotcrete and/or the backfill.

Because of the different geometries of the acrylic vessel and the cavity, only the first few meters of liner around the waist shield make a significant contribution to the corresponding backgrounds listed in Table 1. Specifically, 90% of the background from the steel liner for the top side section is produced in the bottom 2 meters of liner. For the bottom side section of the liner the same fraction of the background is produced in the top 4 meters of the liner. For the bottom section of the liner this fraction is produced within the inner 5.5 meter radius. Therefore it is only recommended that boronation be used in the shotcrete and/or backfill in these restricted regions, unless other considerations make it easier to use boronation throughout the cavity. The background reduction estimate in the previous paragraph was done for these conditions.

Boronated Polyethylene Addition

Since the dominant remaining external background is from the stainless steel liner in the waist region, it is worth while reviewing the question of whether this background can be reduced. It is in fact possible to reduce this background by inserting a 1/2" thick 9% boron loaded polyethylene sheet. Using previous sulfurcrete estimates [2] it appears that a factor of approximately 10 reduction in the waist section stainless steel background should be achievable. This would correspond to an approximately 39% reduction in the total external background in the "extended" case. Initial estimates using boronated concrete with a boronated polyethylene liner indicates that a factor of less than 3 would be achieved, corresponding to an improvement of less than 30% in the total external background. The cost would be at least $450K exclusive of installation costs. Detailed estimates of the improvement that should be obtained with this option should be completed shortly.

The various contributions to chages in the "extended" case background for backfill conditions and boronated poltethylene addition are listed in Table 2.

Phototube and Support Frame

Present plans are to use aluminum hexagonal boxes to house the PMTs, with the hexagons packed within an aluminum geodesic frame. This arrangement is presently being looked at in detail, and a preliminary analysis is presented here. It is assumed that the aluminum has 0.1 ppm U and 1.0

ppm Th in equilibrium to give order of magnitude values for activities. It is also assumed that the *effective* activity of the PMT glass is 100 ppb U/Th to account for the activity level of the other glass components in the phototubes. The (α,pγ) activity in the PMTs has been estimated using the measured Al(α,pγ) yield [4]. The assumption has also been made that comparable contributions come from the boron and sodium in the glass. This results in a factor of approximately 5.7 increase in (α,pγ) yield over that of aluminum alone. A mass of 15.9 and 9.4 tonnes of aluminum for the hexagons and frame, respectively, has been assumed for the calculations. The results in terms of high-energy γ-rays per day released into 4π are shown in Table 3.

These numbers have been compiled in the same format as for the earlier report on an aluminum support structure [3]; as before, the background yield is divided into contributions due to activity in the PMTs ("OLD") and backgrounds due to activities in the aluminum ("NEW"). The "OLD" backgrounds have increased somewhat, due largely to more detailed information about the components. The "NEW" components are also significantly higher than in the earlier report despite a smaller assumed Al(α,pγ) yield. This is basically due to a much greater mass of aluminum. The background values would decrease if the aluminum activity level were decreased. If the uranium level were reduced to 0.1 ppm to be comparable to the thorium, the total aluminum activity would be reduced by a factor of approximately 7. Disequilibrium would also cause a reduction in the background, but it is unlikely to give more than a factor of about 4.

The contribution expected from reflectors has not been included in Table 3. The reflector contribution for glass reflectors can be expected to be at least the same as that of the PMT contribution to the backgrounds. However this must be calculated using more detailed information about the reflector composition and position before a reliable estimate can be provided. Nevertheless, the reflector contribution appears to be a small component compared to that of the hexagons and frame.

The PMT region backgrounds can also be compared directly with the external backgrounds entering the acrylic vessel reported in Tables 1 and 2. If an attenuation factor of 1.2×10^{-4} [5] is used for the source γ-rays of Table 3, a PMT region background level of approximately **0.8 high-energy γ-rays per day** is obtained. This is at least a factor of 30 higher than the external backgrounds and is the dominant background in the detector.

Serious consideration must be given to the use of these amounts and these activity levels of aluminum .

Table 1.
External Backgrounds at 6.0 m Radius (no Backfill)
(x10^-3 gammas(E>5 MeV)/day)

Location	n Source	Target	Shape INCO	Monenco	extended	jug
waist	rock	rock	9.8			
		conc	0.96			
		steel	11.7			
	concrete	r+c+s	1.8			
		total	24.3			
side	rock	steel	1.14	2.38	1.29	1.29
(top)		rock	1.22	2.55	1.38	1.38
(bottom)		steel	1.86	3.62	2.09	0.75
		rock	1.98	3.86	2.23	0.80
		total	6.2	12.4	7.0	4.2
bottom	rock	steel	0.3			
		rock	0.4			
		total	0.7			
top	rock	steel	0.6	1.2	0.6	0.6
		rock	0.1	0.2	0.1	0.1
		total	0.7	1.4	0.7	0.7
		Total	31.9	38.6 (+17%)	32.7 (+2%)	29.9 (-6%)

Table 2.
Alterations to External Backgrounds at 6.0 m Radius
(x10^-3 gammas(E>5 MeV)/day)

Location	n Source	Target	Extended Condition: bare	backfill	0.5% B	bpoly
waist	rock	rock	9.8			9.8
		conc	0.96			0.96
		steel	11.7			1.17
	concrete	r+c+s	1.8			1.8
		total	24.3			13.7
side	rock	steel	1.29	3.10	1.27	
(top)		rock	1.38	0.58	0.58	
(bottom)		steel	2.09	5.06	2.08	
		rock	2.23	0.93	0.93	
		total	7.0	9.7	4.9	
bottom	rock	steel	0.3			
		rock	0.4			
		total	0.7			
top	rock	steel	0.6			
		rock	0.1			
		total	0.7			
		Total	32.7	35.6	30.3	20.0
				(+9%)	(-7%)	(-39%)

Table 3.

Generic 8" PMTs

Source	Yield (E>5 MeV per day into 4pi)	total
"OLD"		
(alpha,pgamma) due to glass	36.0	
PMT (12.4 dynode+0.9 glass)	13.3	
frame due to glass	34.4	
		83.7
"NEW"		
Al hexagons (n,gamma)	442.9(hex)+97.2(PMTs)+69.1(frame)	
Al hexagons (alpha,pgamma)	3861.2	
		4470.4
Al frame (n,gamma)	?(hex)+?(PMTs)+?(frame)	
Al frame (alpha,pgamma)	2272.6	
		>2272.6
	overall total	>6827

References

[1] P. Skensved, H. Lee, B. Bray, E. T. H. Clifford and B. C. Robertson, **Specification Document for Cavity Shielding**, SNO-STR-90-66.

[2] P. Skensved, H. Lee, E. T. H. Clifford and B. C. Robertson, **Summary of Cavity Estimates**, SNO-STR-89-48.

[3] P. Skensved, H. Lee, R. K. Heaton and B. C. Robertson, **The Effect of Aluminum on Backgrounds in the Phototube Region**, SNO-STR-89-83.

[4] K. T. Lesko, E. B. Norman and B. Sur, **High Energy Gamma Rays from the ^{27}Al(α,pγ)** Reaction, SNO-STR-90-2.

[5] P. Skensved, H. Lee, A. McDougall and B. C. Robertson, bf Steel Support and Phototube Backgrounds, SNO- STR-88-50.