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LOW-ACTIVITY CONCRETE PREPARATION AND TESTING

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INTRODUCTION

The Mark II design for the Sudbury Neutrino Observatory detector features a barrel-shaped cavity (maximum diameter 22 m) and a spherical acrylic heavy water tank. Shielding calculations have shown that the original requirements for extra-low activity sulfurcrete shielding (1 m thick) around the entire H_2O tank, at the cavity wall, can be reduced, because of the additional water layer present in the larger cavity.[1] The Mark II design currently specifies a layer of low-activity concrete (with Haley dolomite aggregate and a boron additive) around the waist of the cavity only, with normal concrete filler between the H_2O tank and the cavity rock wall at all other locations. In the investigations described below, low-activity concrete specimens were prepared and evaluated for possible use in the detector shielding.

MATERIALS SELECTION

The goal of this concrete prototype work was the preparation of normal concrete samples, using selected low-radioactivity Portland cement, Haley dolomite aggregate, and a boron additive to enhance the neutron-absorbing properties of the shield. To meet the design parameters used in recent shielding calculations, the concrete should have uranium levels near 300 ng/g, thorium levels near 200 ng/g, and an equivalent boron content of between 0.25% and 1.0%.

A survey of Canada Lafarge cement plants across Canada, was carried out in 1985[2]. Tests of samples of Portland cement from each plant, for uranium and thorium content, were carried out using neutron activation analysis. Using these results, Portland cement samples were obtained from two Lafage plants whose cements previously showed lowest uranium and thorium contents (plant # 9 - 900 ng/g uranium(^{238}U), 3,300 ng/g thorium, and plant # 14 - 1,700 ng/g uranium, 700 ng/g thorium). Crushed dolomite from Timminco Ltd., Haley, Ontario was also obtained for the aggregate (size - 0.25 inch, including about 50 % fines). Borax (sodium tetraborate decahydrate - reagent grade), boric acid, calcium borate and fused sodium tetraborate (glass) were used to provide boron content for some samples.

PREPARATION

Batches of about 10 - 20 kg. concrete were prepared in a standard cement mixer, using a water/cement ratio of 0.50 and aggregate/boron compound proportions listed in Table 1. The boron compounds were generally added in powder form as part of the dry ingredients and a five minute mixing period followed. Moulds for the 3 inch high, 6 inch diameter ring and 1 inch thick cap (for radiation measurements using Marinelli geometry) were filled, and 3 inch diameter, 6 inch high standard strength test moulds were also filled and packed according to test specifications. Samples were sealed for 3, 7 or 21 days (depending on the strength testing planned) and allowed to dry.

TABLE 1: Summary of Concrete Batches Prepared

Batch and Sample	Aggregate and Additive Proportions (wt. %)					Comments
	Cement	Water	Aggregate (dolomite)	Boron Additive	Form	
P - 1	18	9	73	-	-	73-18-9 mix
P - 2	18	9	68.6	4.4	a	0.50% boron
P - 3.1 to	20	9	69.5	1.5	b	0.25% boron
P - 3.5	31	10	57.3	1.5	b	" "
P - 3.6	31	10	56.6	2.2	a	" "
A - 7 (15 samples)	20	9	64	7	c	0.50% boron
A - 8 (5 samples)	20	10	46.7	23.3	c	5.0% boron
A - 9 (7 samples)	20	10	65.4	4.6	c	1.0% boron

a sodium tetraborate decahydrate (borax)
b boric acid
c calcium borate ($Ca(OH)_2 + H_3BO_3$)
d sodium tetraborate (fused - ground)

COMPRESSIVE STRENGTH TESTING

Other than the P - 1 mix (normal concrete), all mixes and samples up to A - 7 were found to be very weak - either crumbling as they were removed from the moulds or showing very low compressive strengths in the testing machine. Tests were carried out on the cylindrical samples following standard CSA procedures.

using a Tinius-Olsen press in the civil engineering laboratory.
Average strengths of the samples of mixes indicated, are listed below:

Table 2: Compressive Strengths

Mix	No. of Samples	Time	Compressive strength (MPa)*
A - 7	5	3 days	11.14 +/- 3.18
	9	21 days	17.45 +/- 2.73
A - 8	2	7 days	6.5
A - 9	7	to be tested	

* the normal concrete P - 1 sample tested at 38.2 MPa (28 day compressive strength)

RADIOACTIVITY ASSESSMENT

Samples of the Portland cements and of concrete from mix P - 1, were tested in the low-background gamma ray spectrometer at the University of Guelph, following standard procedures[4]. Tests of the dolomite aggregate and other concrete batches will be carried out in the near future.

Results are given in Table 3 (below).

CONCLUSIONS

This study has demonstrated that suitable, boron containing low activity concrete of satisfactory strength can be prepared from readily-available materials. Levels of uranium and thorium near 500 ng/g are achievable, and equivalent boron loadings up to 5.0 % appear feasible. Further tests on radioactivity, stability and strength for all concrete specimens are in progress. Measurements of uranium concentration via ^{226}Ra gives concentrations close to 50 % of the ^{238}U measured values, indicating that the uranium chain decay products are not in equilibrium.

TABLE 3: Radioactivity test results ( ) previously-measured.

Material	Content (ng/g)			
	uranium		thorium	potassium
	U(Ra)*	^{238}U		
Portland cement (plant 10)	1090	2010 (900)	4200 (3300)	0.70 %
Portland cement (plant 14)	2360	4070 (1700)	1220 (700)	0.23 %
Haley dolomite		(15)	(15)	
Concrete (Batch # 1)	76	420	560	0.09 %

* These concentrations of uranium are obtained from ^{226}Ra concentrations, assuming equilibrium activities in the uranium decay chain[3].

REFERENCES

(1) E.T.H. Clifford and P.Y. Wong, "Dolomite Concrete vs Sulfurcrete for the 22 Metre Cavity", Sudbury Neutrino Observatory Report SNO 89-R-____, Sept. 20, 1989.

(2) W.F. Davidson, "Portland Cement Radioactivity Survey", private communication, 1985.

(3) R.K. Lewis, P. Jagam and J.J. Simpson, "Radiometric Determination of Low-Level Concentrations of Th, Ra, U and K", Annex 11, Sudbury Neutrino Observatory Main Proposal, 1987.

(4) Canadian Portland Cement Assoc. "Design and Control of Concrete Mixtures", 1984.