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RADIOACTIVITIES OF ROCK SAMPLES FROM SNO CAVITY EXCAVATION

Rock samples were obtained from various depths during excavation of the cavity for the SNO Detector. A set of these samples was recently obtained at the LBL Low Background Facility for gamma-spectrometric analysis of their "natural" radioactive content, namely: the uranium series, the thorium series, and potassium (U,Th,K). The results reported here were obtained with our high-efficiency NaI(Tl) scintillation crystal spectrometer system, referred to as the S7 system. In this analysis protocol we assume there is radioactive equillibrium in both the U-series and the Th-series - - conditions expected to exist in these fresh norite samples. Note that we are not able to detect small quantities of "unnatural" radionuclides (Cs-137, for example); however, none are expected in these fresh materials.

Measurements have already been made within the SNO Collaboration on the radioactive content of rocks collected during the cavity excavation; in that sense, the measurements reported here are "confirmatory" in nature rather than "new information". However, additional measurements on the LBL suite of samples (crushed and sieved) will explore the variation of radiometric content of and Rn-emanation from various size fractions. This new information will be useful in determining the magnitude of the effort undertaken to maintain the detector assembly site as a "dust-free" environment. The key question: does the "dust-size" fraction have significantly higher radioelement content than the bulk rock? This situation has been observed in some other rocks, for example: coarse-grained Sierra Nevada granitic rocks.

Our samples represent 8 different "depths" in the cavity, ranging from the Dome Roof at the top, to the Cavity Floor and the Exit Ramp at the bottom of the excavation. They were collected over the time interval 10/91 to 5/93. Some samples are crushed rock, while others are single pieces. There are as many as four samples from each level, representing material collected from the four cardinal directions (N,S,E,W) as the mining proceeded downward and outward from a centrally located vertical shaft. In most cases we have combined two or more samples from each level for counting together, to provide a single set of (U,Th,K) values for that level. These details are included in the tabulated results on the following pages.

SAMPLE DESCRIPTION		U - ppm	Th - ppm	K - pct
00 ft	Cavity Dome 1057W,1058S,1059E Crushed, 820 grams	1.09+-.02	5.22+-.06	1.158+-.005
08 ft	Cavity Bench 1070N,1071E,1072S Crushed, 808 grams	1.12+-.01	5.55+-.04	1.068+-.003
32 ft	Cavity Bench 1080E,1081W Crushed, 532 grams	1.24+-.01	5.70+-.04	1.083+-.002
45 ft	Cavity Bench 1090S,1091W 2 pc, 955 grams	1.16+-.01	5.40+-.03	0.947+-.002
55 ft	Cavity Bench 1100N,1102S 2 pc, 1021 grams	1.11+-.01	4.69+-.03	0.946+-.002
78 ft	Ramp Base (4ft up) 1113W Crushed, 598 grams	1.00+-.01	4.58+-.04	1.103+-.003
85 ft	Cavity Floor 1120 1 pc, 413 grams	0.98+-.02	4.57+-.06	0.916+-.004
00-85	Avg., 7 levels	1.10+-.09	5.10+-.48	1.032+-.094
85 ft	Ramp (10 ft out) 1060S Crushed, 231 grams	3.54+-.04	22.04+-.16	1.763+-.008

The (U,Th,K) values obtained from the composite samples for each of the 7 levels suggest there may be small decreases in radioelement concentrations toward the bottom of the cavity. However, for practical purposes it is reasonable to assume the cavity has been excavated in a homogeneous body of rock with the radioelement concentrations expressed in the "00-85" averages.

Having attested to the homogeneity of the excavated rock body, measured (U,Th,K) concentrations in the "85 ft Ramp" sample offer contradictory evidence: presence near the cavity of some rock with dramatically higher radioelement content. The sample is only a small quantity (231 grams) of crushed material, some of which has distinctly lighter color than the bulk rock. It may be mainly representative of material that (presumably) occurs in relatively infrequent narrow veins or fracture fillings in the country rock. On-site geologic information probably exists regarding the occurrence of such veins, and hence the significance of the unexpectedly high (U,Th,K) concentrations observed in this single sample. We note this sample does not literally represent material excavated from the cavity itself.

The three samples of crushed material from the Cavity Dome were counted singly with the NaI(Tl) system in a non-standard geometry that gives both good reproduciblity and higher detection efficiency: a uniform thin layer covering the entire 6" diameter area of our "standard" sample container. (The "standard" geometry is a full 1 1/2" thickness in the counting container.) While the resulting values do not represent true absolute radioelement concentrations, they do fairly represent relative sample to sample variations among the radioelements.

SAMPLE DESCRIPTION		U - ppm	Th - ppm	K - pct
00 ft	Cavity Dome 1057W Crushed, 296 grams	1.76+-.03	6.94+-.09	1.517+-.006
00 ft	Cavity Dome 1058S Crushed, 258 grams	1.48+-.02	6.35+-.06	1.374+-.004
00 ft	Cavity Dome 1059E Crushed, 275 grams	1.63+-.03	6.64+-.08	1.598+-.006
00 ft	Avg., 3 Samples	1.62+-.14	6.64+-.30	1.496+-.113

As noted above, further measurements are planned for the LBL suite of SNO Cavity samples, wherein the main emphasis will be to determine variations in radioelement content of and Rn-emanation from the different size fractions obtained after crushing these rocks. Results will be reported promptly to the Collaboration.

VARIATION IN RADIOACTIVITY WITH PARTICLE SIZE

SAMPLE PREPARATION.

All of the above samples, except for the high-activity material of the "85 ft Ramp" sample, were subsequently combined, to constitute 9500 grams total weight of norite. Sized samples were prepared by one of us (S. Flexser), using the well-established procedures described briefly here. The large pieces were first broken up in a large crusher. The bulk of the resulting material that was >0.5 cm in diameter was then passed through a smaller crusher, sieved again, after which the >0.5 cm fraction was re-crushed. The following size fractions were obtained from sieving the fines from this third crushing operation, and were used as the initial samples for high resolution gamma-spectrometric study of the variation in radioactivity with particle size:

>1.18 mm	1000 g	Fraction
0.60 - 1.18 mm	1359 g	Fraction
0.30 - 0.60 mm	706 g	Fraction
124 - 300 um	521 g	Fraction
43 - 124 um	375 g	Fraction.
<43 um	354 g	Fraction
>1.18 mm	5210 g	Residue

Results from these initial samples prompted us to process one additional sample: a <10 um fraction that would be representative of airborne dust. The <43 um fraction was mixed in small batches with distilled water in a blender, briefly sonicated, and left to settle in columns. Suspended material was separated based on the Stokes' Law settling velocity for grains nominally 10 um or smaller (equivalent spherical diameter), and extracted by filtration. This process was repeated until sufficient material was obtained for gamma-spectrometric analysis; final weight of the <10 um fraction so obtained was 55 grams, which is estimated to be about 90% of that originally present in the <43 um fraction. This processing actually produced the two samples:

10 - 43 um	274 g	Fraction
<10 um	55 g	Fraction

RESULTS

Gamma-spectrometric analyses of these 7 samples are summarized in the following table. The measured absolute (U,Th,K) concentrations are given, along with ratios of these values relative to the average values found from the whole-rock analyses listed on page 2 of this report ("00-85 Avg, 7 levels"). We note that the Page 2 table results are from our NaI(Tl) spectrometer system, while the results of the size-fraction study are obtained from high-resolution Ge-crystal spectrometer systems.

To check consistency of the Ge-system results, we can calculate the expected "whole-rock" radioactivities, by combining (U,Th,K) values/weights of the 7 measured size fractions and the 5210 gram residue of >1.18 mm material. Results of these calculations are shown on the line labelled "Total Sample". A check on consistency between NaI results and Ge results is provided by comparison of Ge-system "Total Sample" results with NaI-system "00-85 Avg(7)" results shown on the next line.

SAMPLE	URANIUM		THORIUM		POTASSIUM	
Description	ppm(SD)	Ratio	ppm(SD)	Ratio	pct(SD)	Ratio
>1.18 mm	1.05(.01)	0.92	4.50(.07)	0.92	0.94(.01)	0.92
0.60-1.18 mm	1.00(.01)	0.88	4.38(.07)	0.89	0.95(.01)	0.93
0.30-0.60 mm	1.03(.01)	0.90	4.61(.05)	0.94	1.08(.01)	1.05
124 - 300 um	1.36(.01)	1.19	5.40(.06)	1.10	1.28(.01)	1.25
43 - 124 um	1.85(.01)	1.62	6.56(.09)	1.34	1.64(.01)	1.61
10 - 43 um	2.33(.01)	2.04	11.8(.1)	2.41	1.51(.01)	1.48
<10 um	2.97(.04)	2.60	16.4(.3)	3.34	1.19(.02)	1.17
Total Sample	1.14		4.90		1.02	
00-85 Avg(7)	1.10(.09)		5.10(.48)		1.03(.09)	

Standard deviations appear in parentheses (SD). For the 7 size fraction samples, SD's are derived from counting statistics alone. SD's listed with the "00-85 Avg(7)" entry reflect the range of values obtained from separate analyses of the samples from which these averages are computed; counting statistics for individual analyses are given on the Page 2 table.

The (U,Th,K) concentrations are seen to vary with particle size, and in general increase with decreasing particle size. For thorium, the "dust-sized" fraction is enriched a factor of 3.3 in comparison to the "Total Sample" bulk rock. For uranium, an enrichment factor of 2.6 is observed. For potassium, the enrichment factor is only 1.2 in the "dust" fraction, while the greatest enrichment (1.6) is found in a significantly larger particle-size fraction.

Among the natural terrestrial radioactivities, thorium "contamination" poses the greatest threat to maintaining an acceptably low BKG level in the SNO detector. The outcome of the present study certainly emphasizes the importance of providing a "dust-free" environment during construction of the entire detector assembly, and in fact suggests that only 1/3 as much total "dust" can be tolerated as was previously estimated.

Several samples of real "mine-dust" are to be collected by LBL personnel on a current visit to the mine. The real dust (U,Th,K) radioactivities will be compared to results obtained from our artificially created "dust" that are documented in this summary. In addition, measurements of Rn-emanation will be made on the real dust samples, as well as on some of our crushed and sized materials.