

Thorium and Iron Content of Mine Dusts

R. G. Stokstad

Lawrence Berkeley Laboratory

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Abstract

The thorium content of mine dust collected at various locations along the drift to the SNO site has been measured with several techniques - direct counting, proton induced x-ray emission, x-ray fluorescence, and neutron activation analysis. The thorium content varies significantly, from a minimum of 4 ppm to a maximum of 24 ppm (from direct counting measurements). The average Th content of the six samples obtained by direct counting and by XRF measurements is a factor of two higher than the value of 5 ppm (for norite) that we have used in cleanliness calculations. The larger average concentration of Th in dust that enters the cavity via equipment and personnel therefore suggests that cleanliness requirements be tightened by a factor of 2. The results for Fe indicate a positive, though not complete, correlation with the Th content. Measuring the Th content in dust via the Fe component thus provides some help in correcting for fluctuations in Th content. Additional measurements are suggested.

I. Introduction

The location of the SNO site underground was chosen partly because of the low thorium content of the predominant rock (norite). A series of core samples¹, taken at 20 ft intervals and over a range of about 100 feet, showed variations in thorium from a minimum of 2.8 ppm to a maximum of 7.4 ppm. The thorium content at the location of the cavity is given in ref. 1 as 3.3 ppm. The percentage by weight of Fe in different samples in Table 2 of ref. 1 varies from 5.5% to 7.1% with the value at the site being 5.78%. The iron and trace elements present at the level of a few percent are of interest because they can be used in conjunction with x-ray fluorescence to measure small amounts of mine dust.

The composition of mine dust brought into the laboratory as contamination during the clean construction period and regular

operation of the detector will reflect mainly the composition of the fine particulate (dry powder, airborne dust, and fine mud) encountered along the drift from the shaft elevator to the SNO site. Part of this drift serves a working section of the mine and will necessarily contain particulate from nickel ore and rocks other than norite. It is therefore important to measure the thorium content of dusts found along this route. To this end H. Evans collected samples² from the floor of the drifts at six locations between the number 9 shaft and the SNO site, as shown in Figs. 1 and 2. The samples consisted of dust (powder), grains, and small pebbles mixed together. Portions of the samples from these areas have been analyzed by various techniques including direct counting³, proton-induced x-ray emission (PIXE)⁴, x-ray fluorescence (XRF)⁵, and neutron activation analysis (NAA)⁶. This report summarizes results of these measurements mainly as they pertain to the thorium and iron content. Measurements of norite core samples and of dusts collected at the SNO site are also given for comparison. The results from the individual measurements³⁻⁶ will likely be reported separately and in more detail than here.

II. Results

A. Direct Counting

The results of direct counting measurements³ made at Laurentian U. by E.D. Hallman using the 4600' underground laboratory are given in Table 1 and shown in Figs. 3 and 4. Note that all fractions (ppm, %) given in this report are by weight.

Table 1

No.	Th(ppm)	U(ppm)	K(%)	Th/K	U/Th
1	6.42 (15)	1.19 (11)	1.16 (1)	5.5	0.19
2	5.12 (49)	1.02 (14)	1.10 (3)	4.7	0.20
3	7.13 (16)	1.33 (4)	1.26 (1)	5.7	0.19
4	24.1 (2)	4.09 (6)	2.88 (1)	8.4	0.17
5	9.15 (9)	1.34 (7)	1.41 (1)	6.5	0.15
6	4.01 (10)	0.87 (8)	0.88 (1)	4.6	0.22

The mass of a sample was typically 3-4 kg, and it included powder, lumps, grains, and pebbles.

B. Proton Induced X-Ray Emission

The results of PIXE measurements⁴ made by J.D. MacArthur at Queens U. are given in Table 2 and shown in Fig. 3.

Table 2

Sample	Th(ppm)	Fe(%)	Th(ppm)/Fe(%)
2	4 (2)	7.0	0.57 (29)
3	7 (4)	15.3	0.46 (26)
4	11 (3)	3.9	2.8 (8)
5	4 (1)	6.5	0.61 (15)
6	<2	6.8	<0.3
nor.	2 (2)	7.6	0.26 (26)

The amount of the sample that was exposed to the proton beam was typically 0.5 mg. The last entry in the table is for a sample of norite.

C. X-Ray Fluorescence

The results of XRF measurements⁵ made by R. Giauque at LBL are given in Table 3 and Figs. 3-6 for Th, Fe, and K. Complete results for all trace elements measured are tabulated in the Appendix.

Table 3

No.	Th(ppm)	Fe(%)	K(%)	Th/Fe	Th/K
1	14 (3)	18.7 (15)	1.28 (18)	.75 (15)	10.9 (23)
2	10 (2)	10.8 (5)	1.23 (12)	.93 (20)	8.1 (18)
3	12 (2)	13.4 (6)	1.59 (16)	.89 (20)	7.5 (15)
4	20 (2)	5.1 (3)	3.04 (20)	3.9 (2)	6.6 (8)
5	9 (2)	9.9 (5)	1.18 (12)	.91 (20)	7.6 (17)
6	6 (2)	6.8 (3)	1.03 (10)	.88 (30)	5.8 (19)
nor.	5.4 (7)	7.02 (6)	1.15 (10)	.77 (10)	4.7 (6)

The amount of material (dust powder) fluoresced by the x-ray beam was typically 100 mg. Lumps and large grains were removed from samples 1-6 and the remaining powder pressed together. The sample labelled "nor." was obtained by taking a chip from a rock collected at the SNO site and grinding that chip into a powder. The values given are the average of three measurements made on different portions of the ground powder.

D. Neutron Activation Analysis

One or two small (several mm in size) pebbles with a total weight of about 100 mg were selected from samples 2 and 4, washed to remove any dust, and were then irradiated with neutrons. (Pebbles were used and the dust washed off in order to avoid having to work with dispersible radioactivity. The pebbles were lighter in color than the other material.) A sample of norite, obtained by taking a 660 mg chip from a rock collected at the SNO site was also analyzed. The results of these measurements, made at LBL by E. Norman and M.T.F da Cruz⁶, are given in Table 4 and shown in Fig. 3.

Table 4

No.	Th(ppm)	Fe(%)	Th/Fe
2	3.4 (3)	1.72 (17)	2.0 (3)
4	3.9 (4)	1.63 (16)	2.4 (3)
nor.	4.3 (4)	5.9 (6)	0.73 (10)

Note that the norite samples listed in Tables 3 and 4 were obtained from the same piece of rock collected at the SNO site.

III. Discussion

A. Comparison of the Different Measurement Techniques.

It is difficult to assess the accuracy of the different methods by intercomparison of the present results because measurements have not been made on exactly the same sample material. Nevertheless, the measurements made on "norite" samples or samples collected at the SNO site seem to show quite similar values for the Th and Fe content. In one case, analyses (with NAA and XRF) were made on samples that came from the same piece of rock. The agreement was good. The measurements of potassium content by XRF and by Direct Counting agree very well (Fig. 4). The PIXE results have large errors, but seem to follow the trends (from sample to sample) indicated by the other methods. The Direct Counting and XRF measurements of Th content also exhibit the same trends, but three of the data points differ by two to three standard deviations. In general, some differences in the results might be ascribed to non-uniformity in the particular samples analyzed. Such non-uniformity can arise from the different amounts of material in a sample (milligrams vs. kilograms)

and from the selection of the particular specimen to be analyzed from the aggregate of material collected at that location. While we do not have the kind of data that enables precise evaluation of the accuracies of the individual techniques, we have no reason to believe that any of the three methods is in serious error, and we have a qualitative indication that all three are giving good results for the specimens they encountered.

B. Variations in Thorium Content

The present collection of results obtained by these four different techniques shows that the amount of thorium in mine dusts encountered along the drift can vary considerably. Near the shaft (sample locations 1-3) the thorium content is about a factor of two higher than near the cavity (location 6, and norite). The average of all XRF and Direct Counting measurements of thorium content at locations 1-6 is 10 ppm.

Sample 4 is interesting. Three of the four measurements show a high Th content (absolutely and relative to other samples when analyzed by the same technique). The NAA measurement of the pebble selected from the sample material, however, is low in Th and even lower in Fe. Indeed, this measurement reminds us that, when dealing with an aggregate such as the present sample material, we should not expect elemental or chemical uniformity when small-scale portions of the aggregate are examined. (We recall that the pebble selected for the NAA measurements of material from location 4 had a different color than the rest of the material collected in that sample. The pebbles selected for this NAA analysis were also very low in Fe.) It appears that the pebbles selected for NAA from the material collected at sites 2 and 4 are atypical of the rest of the material collected at these locations and analyzed by the other methods.

C. Thorium Content Relative to other Trace Elements

The XRF measurements (Fig. 5) and Direct Counting measurements (Table 1) reveal a strong correlation between the K content and the Th content. A similar correlation between Fe and Th is also shown by the XRF measurements with the lone exception of the sample from location 4 (see Fig. 5). Fig. 6 shows all the measured values of the Th/Fe ratio for all the samples from the six locations plus various samples that are considered to be norite. Note that these involve different samples, widely different amounts of

analyzed material (kg to mg), different physical types (pebbles to powder), and measurement techniques with varying precision. In Fig. 6 the correlation appears less pronounced, with four measurements giving values for $\text{Th}(\text{ppm})/\text{Fe}(\%)$ between 2 and 4, and fourteen measurements clustering around 0.7. The average of all 18 measurements is about 1.1.

Given a positive correlation between the Th and Fe contents, estimates of the amount of Th based on a measurement of Fe and assuming a constant ratio (Th/Fe) will, on average, be more accurate than estimates based on the total mass of the dust and assuming a constant Th(ppm) concentration. We can get a crude idea of how much this correlation helps by looking at the present results. The average of all Th content measurements (not weighted by errors) is 7.9. The average of all Th/Fe ratios is 1.1. When we compare these with the values we had been using in cleanliness estimates (5 ppm of Th and $5/6=0.83$ for the ratio), we see that we err by the factor $7.9/5=1.6$ if we measure total mass, while we err by the smaller factor $1.1/0.83 = 1.3$ if we base our measurement on the Fe content.

We could also assume that the dust found at each of the six locations contributes one-sixth of the total amount of contamination to enter the laboratory. Taking the XRF measurements as representative, the average Th content is 12 ppm, which is a factor of $12/5 = 2.4$ times higher than the value (5 ppm) we have been using up to now. On the other hand, the average Th/Fe ratio is 1.5, which is a factor of $1.5/0.83 = 1.8$ times higher than the average Th/Fe ratio we have been using. Again, the difference between 2.4 and 1.8 is in the right direction and shows that the Th and Fe correlation helps correct for variations in the thorium content.

An even better correlation exists between the potassium and thorium contents (Figs. 4 and 5). However, the measurement of potassium content in thin samples (a few $\mu\text{g}/\text{cm}^2$ of dust) by XRF analysis is made difficult by the lower concentration of K compared to Fe, the lower excitation and fluorescence yields for K, and the degeneracy of the $\text{K}(\text{K}_\alpha)$ line with the $\text{Ar}(\text{K}_\beta)$ line from the Ar present in air. This results in a reduction in sensitivity to mine dust by a factor of at least 25. Although the above considerations on Th and Fe correlations in mine dusts are hardly sophisticated statistical analyses, they do suggest that measuring the Fe is the next best thing to measuring the Th.

Tightening the cleanliness constraints by a factor of 2 (so that instead of 0.4 microgram/cm² of mine dust we are permitted only 0.2 microgram/cm²) and measuring the mine dust by assuming a ratio of Th/Fe = 0.83 would be a satisfactory response to the new information from these measurements. Whether these constraints can be achieved and at what price is another question. But it bears consideration.

IV. Conclusions

The dust accumulated by personnel and material as they pass along the drift from the shaft to the SNO site has a higher average Th concentration than norite. This suggests reducing the allowable amount of mine dust in the cavity by a factor of 2. Measuring the mine dust by means of the iron in the dust reduces somewhat the uncertainty in the amount of Th present because of the positive correlation between Th and Fe.

Variations in Th and Fe content and in the Th/Fe ratio are found in material collected from the same location depending on whether the specimen analyzed is a powder or a pebble.

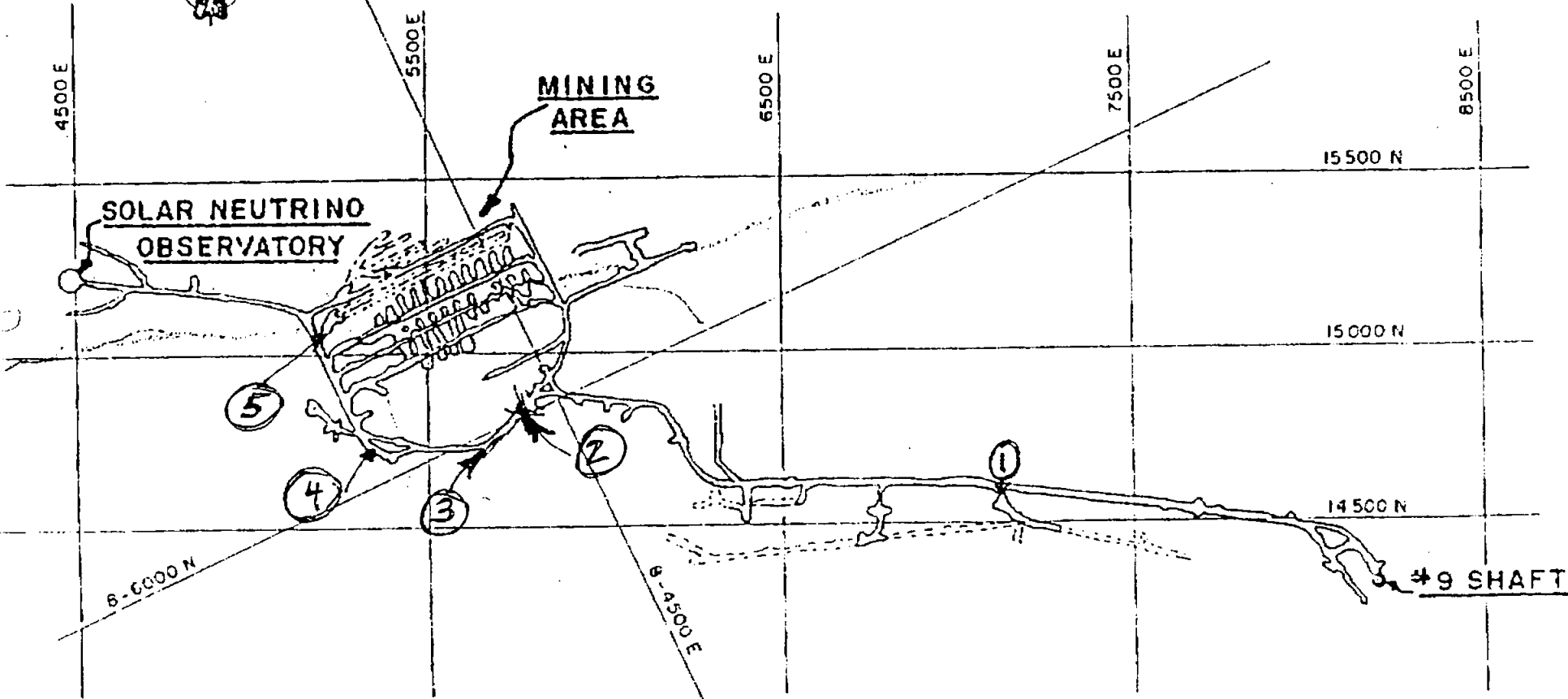
Since the contamination that enters the laboratory will be in the form of fine particulate rather than pebbles, it seems highly desirable to analyze only the fine material from each location. This could be done with the existing samples. In the future, another and perhaps better way to do this would be to collect dust in quantity in the dirty areas at the entrance to the laboratory (e.g., from drains in the car wash and personnel entry, and from the bag filter at the fresh air intake) and measure the Th content and Th/Fe ratio. Perhaps sufficient dust can be collected directly from clean surfaces of the detector (although we hope this will be difficult to do!) and sufficiently sensitive measurement techniques can be applied to enable occasional measurements of the average Th content and Th/Fe ratio in microscopic samples of air-deposited dust. In this case the cleanliness requirements could be adjusted with the greater certainty. E. Norman has suggested that NAA might be a sufficiently sensitive technique for this application.

Acknowledgements

H. Evans is acknowledged for initiating this study and for collecting and distributing the samples. E.D. Hallman, J.D. MacArthur, and E. Norman kindly communicated results prior to reporting them to the Collaboration. I thank R. Giaque for the careful, expert manner in which he has analyzed these and other dust samples for us. E. Kong helped with many aspects of this and related work.

References

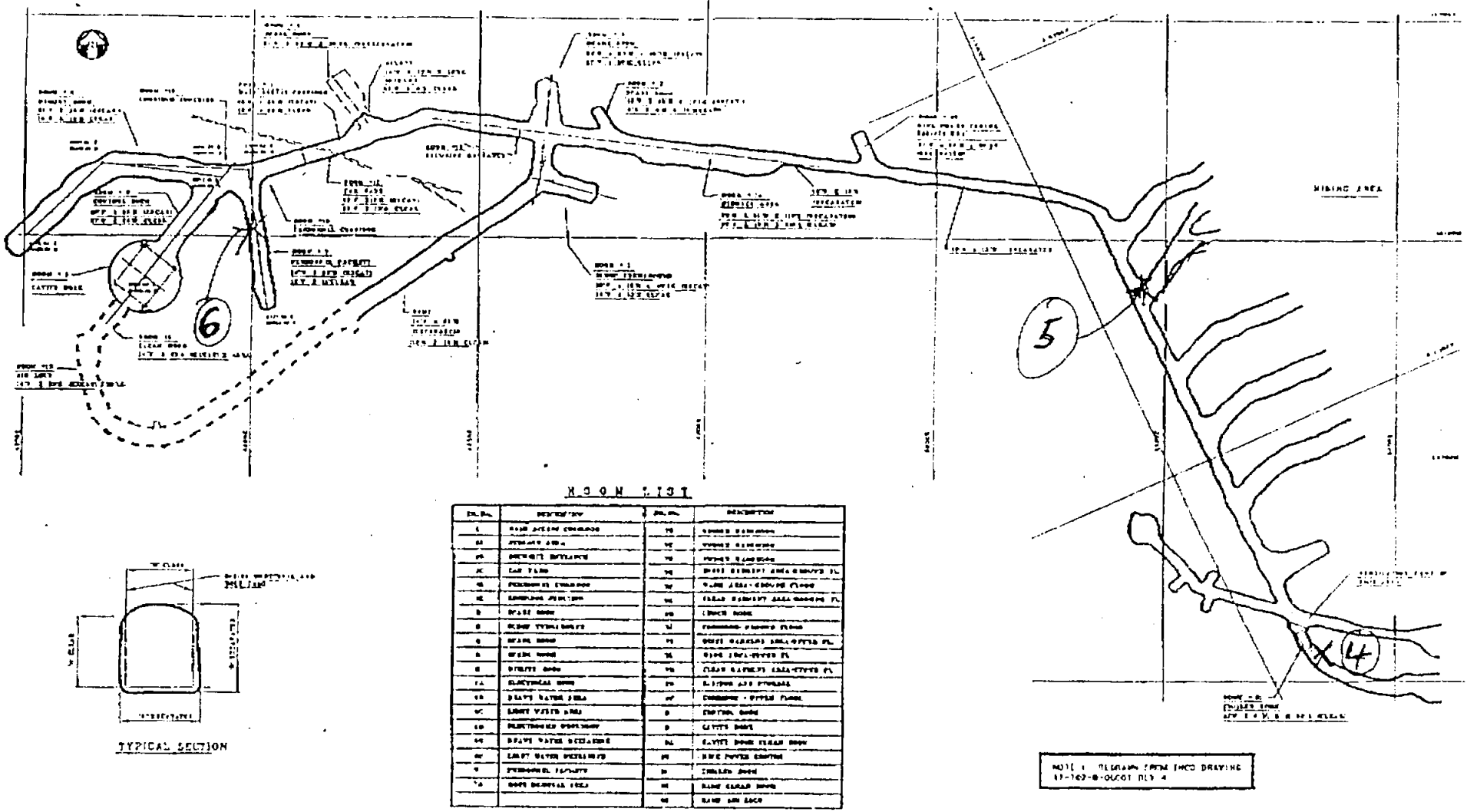
1. "Composition of Norite Host Rock and Sulfurcrete," R.K. Heaton, W.F. Davidson, H.W. Lee, P. Skensved, and B.C. Robertson. Annex 9, SNO-87-12, November 1987.
2. H. Evans, private communication.
3. E.D. Hallman, private communication.
4. J.D. MacArthur, private communication.
5. R. Giaque, private communication.
6. "Measurements of Th/Fe Ratios in Rocks Collected in and around the SNO Detector Site," E.B. Norman and M.T.F. da Cruz, SNO-STR-92-074, October, 1992, and private communication.



CREIGHTON # 9 SHAFT

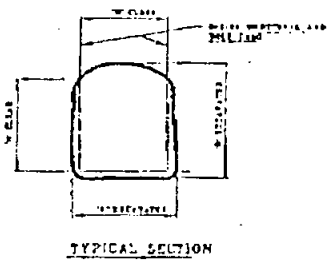
PLAN - 6800 L

Fig 1



ROOM LIST

NO.	DESCRIPTION	NO.	DESCRIPTION
1	RAIL ROOM	25	WATER STORAGE
2	PERSONNEL ROOM	26	WATER STORAGE
3	DRIFT ROOM	27	WATER STORAGE
4	DRIFT ROOM	28	WATER STORAGE
5	DRIFT ROOM	29	WATER STORAGE
6	DRIFT ROOM	30	WATER STORAGE
7	DRIFT ROOM	31	WATER STORAGE
8	DRIFT ROOM	32	WATER STORAGE
9	DRIFT ROOM	33	WATER STORAGE
10	DRIFT ROOM	34	WATER STORAGE
11	DRIFT ROOM	35	WATER STORAGE
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13	DRIFT ROOM	37	WATER STORAGE
14	DRIFT ROOM	38	WATER STORAGE
15	DRIFT ROOM	39	WATER STORAGE
16	DRIFT ROOM	40	WATER STORAGE
17	DRIFT ROOM	41	WATER STORAGE
18	DRIFT ROOM	42	WATER STORAGE
19	DRIFT ROOM	43	WATER STORAGE
20	DRIFT ROOM	44	WATER STORAGE
21	DRIFT ROOM	45	WATER STORAGE
22	DRIFT ROOM	46	WATER STORAGE
23	DRIFT ROOM	47	WATER STORAGE
24	DRIFT ROOM	48	WATER STORAGE
25	DRIFT ROOM	49	WATER STORAGE
26	DRIFT ROOM	50	WATER STORAGE



NOTE: TELEGRAM FROM INCO DRAFTER
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Fig 2

CADD DRAWING

Thorium Content

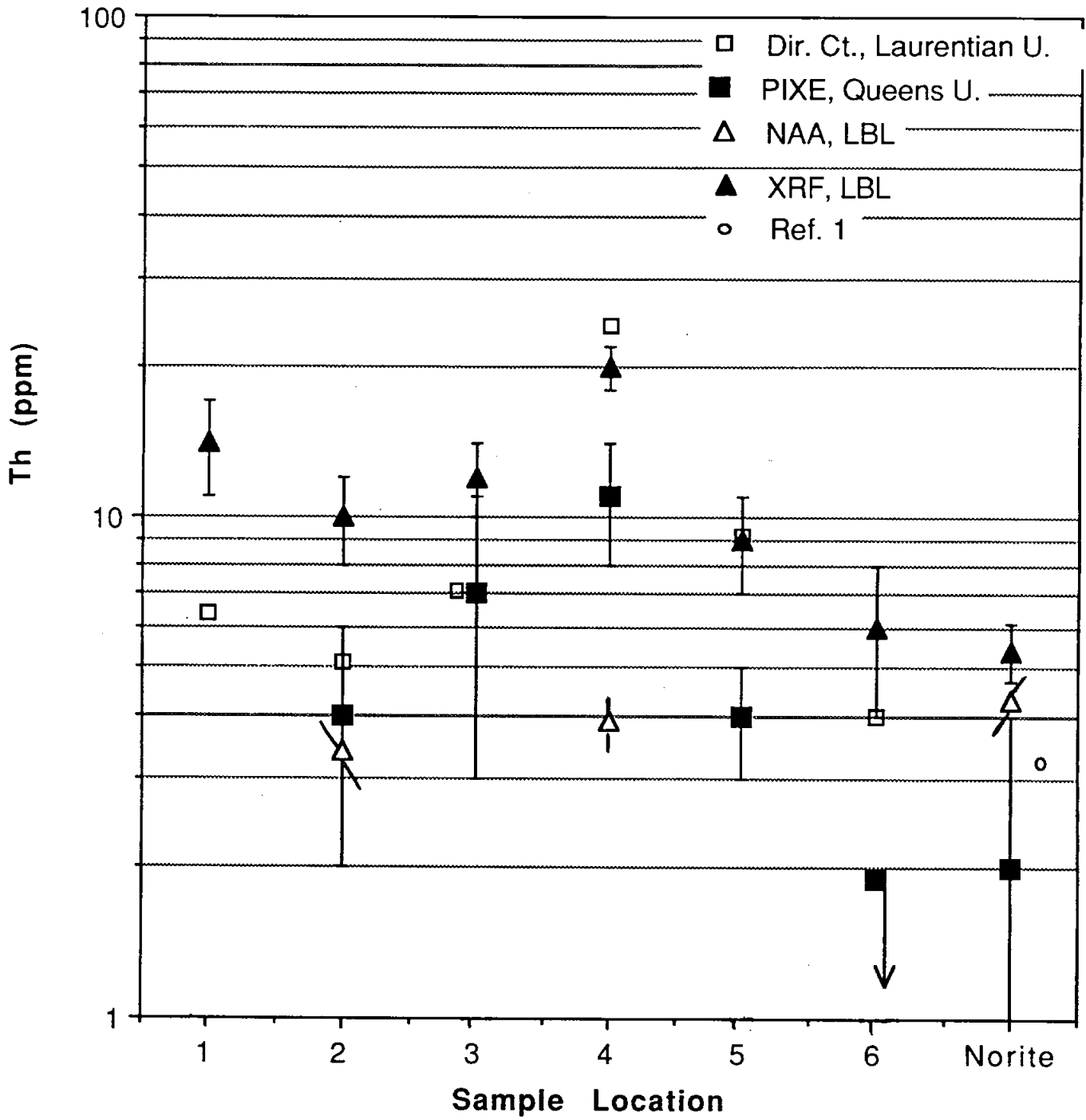


Figure 3.

Potassium Content

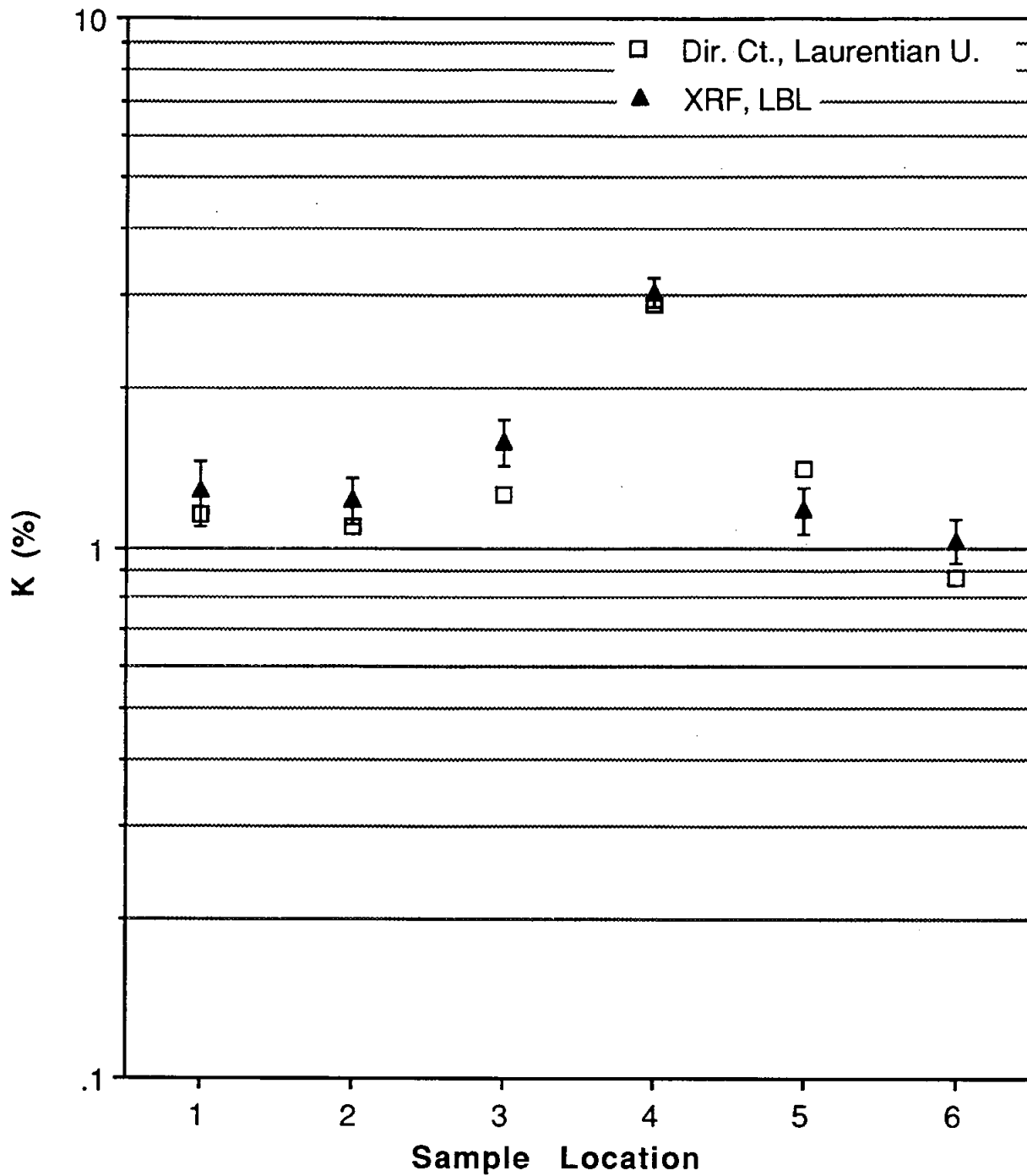


Figure 4.

XRF Measurements of Th(ppm), Fe(%), K(%)

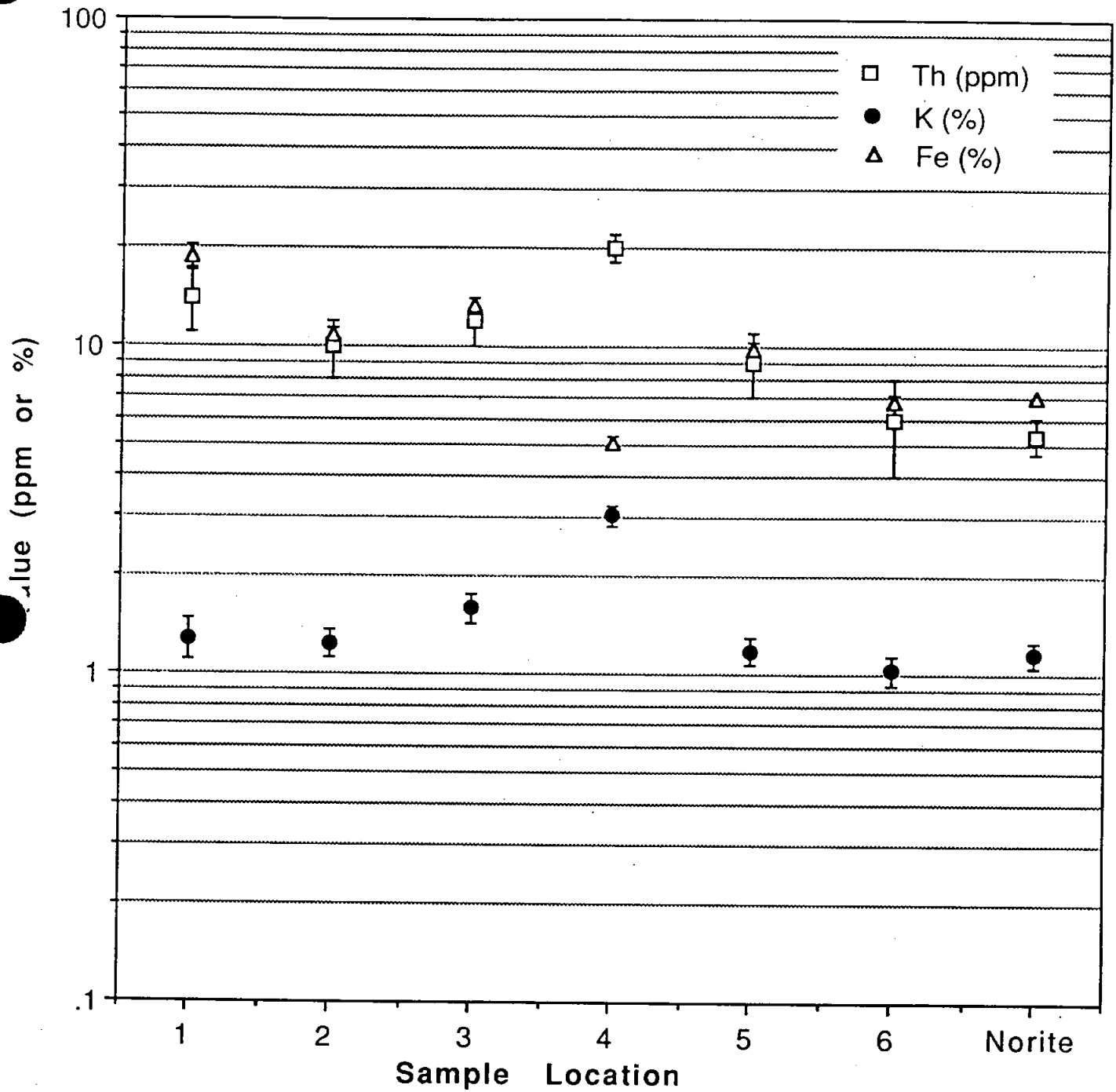


Figure 5.

Thorium to Iron Ratio

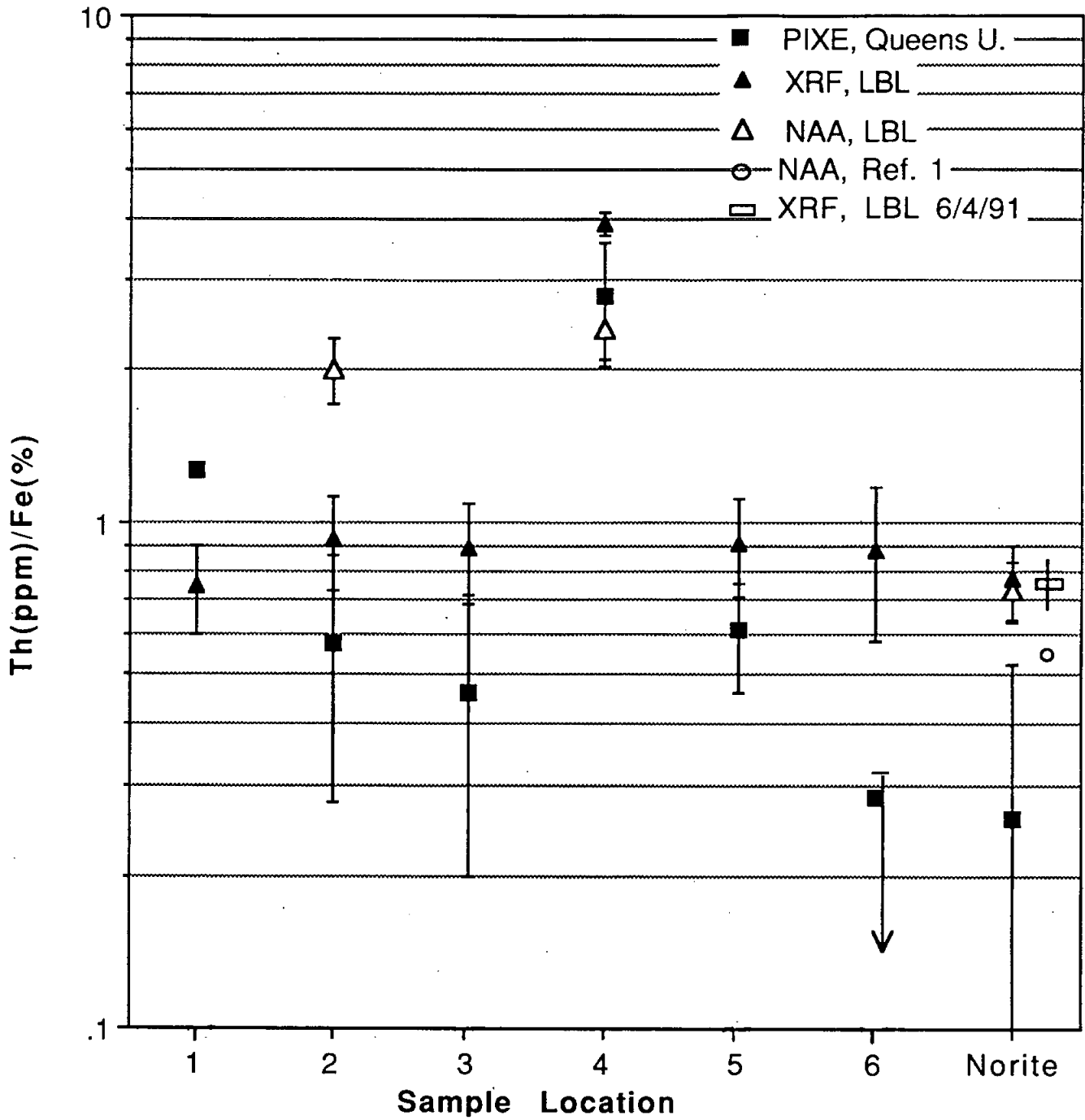


Figure 6.

XRF Table

X-ray fluorescence analysis of mine dust samples collected by H. Evans												
Sample No.	#1		#2		#3		#4		#5		#6	
Sample ID	20/5/92-1		20/5/92-2		20/5/92-3		20/5/92-4		20/5/92-5		20/5/92-6	
Element	Value	Error	Value	Error	Value	Error	Value	Error	Value	Error	Value	Error
K (%)	1.28	.18	1.23	.12	1.59	.16	3.04	.20	1.18	.12	1.03	.10
Ca (%)	2.95	.30	5.60	.50	4.70	.40	3.29	.20	6.10	.50	5.08	.30
Ti (%)	0.28	.03	0.30	.03	0.33	.03	0.34	.02	0.29	.03	0.46	.03
Mn (ug/g)*	1300	100	1200	100	1300	100	680	40	100	100	1070	80
Fe (%)	18.7	1.5	10.8	0.5	13.4	0.6	5.09	.25	9.9	0.5	6.84	.27
Ni (ug/g)*	26000	2000	6700	400	9900	500	303	15	13300	600	490	25
Cu " "	12000	1000	4600	300	5700	400	76	6	4100	200	419	20
Zn " "	320	20	320	20	280	20	63	4	280	20	116	6
Ga " "	35	10	15	4	22	4	20	2	20	3	20	2
As " "	6	3	10	3	8	3	3	2	5	3	2	2
Se " "	28	3	7	2	11	2	<2		8	2	<2	
Rb " "	47	3	52	3	63	3	130	5	46	3	34	2
Sr " "	121	6	160	8	173	9	150	6	180	8	399	16
Y " "	22	2	23	2	27	2	57	3	30	2	18	2
Zr " "	130	7	121	6	144	7	325	13	167	7	134	5
Nb " "	9	2	10	2	12	2	33	2	12	2	5	1
Pb " "	35	5	45	4	55	6	27	3	36	4	21	3
Th " "	14	3	10	2	12	2	20	2	9	2	6	2
Ba " "	<200		160	40	370	50	780	80	510	60	390	40
Footnote												
*ug indicates microgram												
Notes: Sample 1 had to be diluted 1.00 : 3.00 with Na ₂ CO ₃ prior to analysis due to the due to the high Fe content. Similarly, 2,3, and 5 had to be diluted 1.00 : 1.00 with NaCO ₃ .												