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No. 1670

NEUTRON-ACTIVATION ANALYSIS OF ROUTINE MINERAL-PROCESSING SAMPLES

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NATIONAL INSTITUTE FOR METALLURGY

NASIONALE INSTITUUT VIR METALLURGIE

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NEUTRON-ACTIVATION ANALYSIS OF ROUTINE MINERAL-PROCESSING SAMPLES

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SYNOPSIS

Instrumental neutron-activation analysis was applied to a suite of typical mineral-processing samples to establish which elements can be rapidly determined in them by this technique.

A total of 35 elements can be determined with precisions (from the counting statistics) ranging from better than 1 per cent to approximately 20 per cent. The elements that can be determined have been tabulated together with the experimental conditions, the precision from the counting statistics, and the estimated number of analyses possible per day. With an automated system, this number can be as high as 150 in the most favourable cases.

SAMEVATTING

Instrumentele neutronaktiveringsanalise is toegepas op 'n reeks tipiese mineraalverwerkingsmonsters om vas te stel watter elemente vinnig deur middel van hierdie tegniek in hulle bepaal kan word.

Altesame 35 elemente kan bepaal word met 'n presisie (vanaf die tellende statistiek) wat wissel van beter as 1 persent tot ongeveer 20 persent. Die elemente wat bepaal kan word, is getabelleer tesame met die eksperimentele toestande, die presisie vanaf die tellende statistiek, en die geraamde getal ontledings wat per dag gedoen kan word. Met 'n geoutomatiseerde stelsel kan hierdie getal in die gunstigste gevalle so hoog as 150 wees.

CONTENTS

1. INTRODUCTION

Since the advent of the Ge(Li) detector, instrumental neutron-activation analysis has been successfully applied to the analysis of a wide variety of samples and to the determination of more than half of the elements in the periodic table[1]. In most applications the emphasis has been on the determination of trace elements. For example, in the Activation Analysis Research Group this technique has been applied to the determination of a number of trace and minor elements in many geological materials[2,3].

It has been pointed out[4] that the characteristics of activation analysis that give it great sensitivity in the determination of trace elements can be transformed into speed of analysis where the element is present in major amounts. A theoretical assessment of the problem indicated that the technique should prove to be of great use in the analysis of many types of routine samples and that the analysis can be carried out rapidly. This assessment was followed up by the development of a method for the determination of vanadium and titanium in titaniferous magnetite, and a method for the determination of uranium in a variety of samples[5].

Since a theoretical survey cannot allow for the practical problems that are encountered with real samples, such as matrix interference, the present project was undertaken to assess experimentally what elements can be determined in a suite of samples of routine analytical interest. The objective was to establish whether the element of interest can be determined, and the speed and precision that is attainable by this technique.

A suite of fifteen typical mineral-processing samples was accordingly selected. It included lead, copper, and zinc ore concentrates, ferrochromium and chromite samples, samples of a matte-leach residue resulting from platinum extraction, and ore samples. The sample suite is described in Table 1.

There are many other types of samples that could be analysed, but the basis for the choice of the above suite of samples was their relevance to the research programmes of the National Institute for Metallurgy and their potential suitability for analysis by instrumental neutron-activation analysis with a rapid turn-around time.

The procedure in instrumental-activation analysis consists of four different steps:

(a) the weighing and encapsulation of the powdered sample,
(b) the irradiation of the sample for a time, *Ti*,
(c) the measurement of the gamma spectrum from the sample after a delay time, *Td*, for a counting time, *Tc*, and
(d) the calculation and reporting of results.

In this programme, the irradiations were carried out in the reactor SAFARI I, a 20 MW ORR pool-type reactor. This is primarily a materials-testing reactor and is not designed specifically for activation analysis. The facilities available thus imposed certain constraints on the programme.

In a given sample, the elements that can be determined will depend on the values that are used for the irradiation time and the decay time. The ultimate precision also depends on an optimum choice of these parameters. In the present work, the results quoted are for decay times varying between 1 minute and 2 days. The lower limit was set by the restrictions imposed by the irradiation facilities, and the upper limit was set as the maximum turn-around time acceptable with routine samples.

The limiting precision that is obtainable is also strongly influenced by the counting time used. In general, the coefficient of variation from the counting statistics varies as the inverse of the square root of the counting time. There is thus a trade-off between the number of samples that can be analysed and the ultimate precision obtainable.

In the estimation of the number of analyses possible per day by the technique, a precision of better than 1 per cent from the counting statistics was aimed at in the determination of the major elements, or the elements of primary importance. Where the precision obtainable with a counting time of 200 seconds was better than this, the reported counting time was reduced in order to increase the sample throughput. On the other hand, the reported counting time was limited to less than 500 seconds so that a sample throughput of at least 50 samples a day could be maintained.

In the estimation of the number of analyses possible per day, it was assumed that the total analysis time is only slightly greater than the counting time. This assumption is justified under the

TABLE 1

The sample suite

No.	Identification of sample		Remarks
1	Copper ore (Phalaborwa)	7/69	Cu ore std, low Cu (≈ 0,038 %)
2	Copper ore (Tsumeb)	15/69	Cu ore std, high Cu (14,1 %)
3	Copper concentrate	OPH 264-5	Flotation concentrate from Cu-Zn ore (≈ 20 % Cu, ≈ 4 % Zn, ≈ 18 % Pb)
4	Zinc concentrate	OPH 264-7	Flotation concentrate from Cu-Zn ore (≈ 51 % Zn, ≈ 0,3 % Cu, ≈ 0,2 % Pb)
5	Lead concentrate	OPH 258-7	Flotation concentrate from Cu-Zn ore (≈ 20 % Pb, ≈ 1,4 % Cu, ≈ 7,6 % Zn)
6	Lead concentrate	OPH 260-8	Flotation concentrate from Cu-Zn ore (≈ 50 % Pb, ≈ 4,9 % Cu, ≈ 32 % Zn)
7	Chromite	PH 783-6	≈ 34 % Cr, ≈ 22 % Fe, ≈ 26 % SiO_2
8	High-silicon ferrochromium	PH 691-5	≈ 29 % Cr, ≈ 27 % Fe, ≈ 34 % SiO_2
9	Ferrochromium	PH 798-1	≈ 47 % Cr, ≈ 39 % Fe, ≈ 9,8 % SiO_2
10	Platinum ore	PT 01	
11	Matte-leach residue	22/72	
12	Matte-leach residue collected in nickel sulphide	FF 88	
13	Manganese ore	21/67	
14	Iron ore (Sishen)	SS06/C	
15	Pegmatite		

following conditions.

(1) Sample preparation consists only in weighing out a portion of the powdered sample into a polyethylene vial (as is done in the preparation of samples for irradiation in the pneumatic facility of SAFARI 1, and for all irradiations in a TRIGA reactor).

(2) The extraction of peak areas and the calculation of results is done by a small computer or a programmable calculator interfaced to the multichannel analyser.

2. EXPERIMENTAL METHOD

2.1. IRRADIATION IN THE PNEUMATIC FACILITY

A 50 mg portion of each of the sixteen samples was weighed into a 3 cm^3 polyethylene container with a snap top. This container was placed centrally in a polyethylene rabbit and irradiated for either 10 or 20 seconds in the pneumatic irradiation facility of SAFARI 1. The gamma spectrum from each sample was measured after decay times of typically 1 min, 5 min, 10 min, 60 min, and 1 day. The measurement was made using a 40 cm^3 Ge(Li) detector connected to a Packard 4096-channel pulse-height analyser.

For each measurement, the distance between the detector and the sample was adjusted so that the dead time of the analyser was approximately 20 per cent at the beginning of the counting period. Counting periods were typically 200 seconds at the short decay periods, and either 500 or 1000 seconds at the longer decay periods.

2.2. IRRADIATION IN THE HYDRAULIC FACILITY

Seven of the samples were selected for an assessment of the elements that can be determined with a longer irradiation time.

A 200 mg portion of each of these samples was weighed into a fused-silica tube with an internal diameter of 3 mm. The seven samples were placed in an aluminium can and irradiated for 30 minutes in the 1 West position of the hydraulic irradiation facility. After a decay time of 4 days, the samples were counted for 10 minutes each under the same conditions as those described above.

2.3. EVALUATION OF THE DATA

The spectral data were recorded on magnetic tape and were processed by the computer programme ARGTUB, which is based on Yule's HEVESY programme[6]. It locates peaks, integrates them, calculates the error in the peak area from counting statistics, and provisionally identifies the peaks.

Lists were drawn up of the error in the peak area at the different decay times, and on the basis of these lists the identification of the peaks was confirmed, suspect peaks were eliminated, and the optimum decay times were selected. In the sample of matte-leach residue, for example, 71 peaks were evaluated.

3. RESULTS

A total of 48 isotopes were identified and 38 different elements could be determined in the samples. The elements that were determined are shown in Table 2, which also gives the total number of samples in which each element was determined.

The most favourable experimental conditions were determined for each element in each sample, and the expected precision from the counting statistics and the number of samples that can be determined per day were established according to the guidelines outlined in Section 1. These results are given in full in the Appendix and they are summarized in Table 3, which gives the precisions obtainable. It is estimated that with a fully automated system these precisions could be obtained with a throughput of between 50 and 150 samples a day.

4. DISCUSSION

The precision of the determinations quoted there is that due to counting statistics, and it does not take into account other sources of uncertainty. It is considered that contributions from other sources due to flux-monitoring uncertainties, counting geometry, and dead-time corrections can be reduced to less than 1 per cent in the coefficient of variation. This means that the overall precision would be between 1 and 1,5 per cent in the best cases.

If better precision is required, it can be obtained at the expense of sample throughput. If it is necessary to improve the precision from the counting statistics by a factor of 2, the sample throughput will be reduced by a factor of 4. *Vice versa*, if a poorer precision can be tolerated, the sample throughput can be greatly increased. In some cases several elements can be determined simultaneously, and the time per determination will then also be greatly reduced.

For a large throughput of samples, a degree of automation is essential. One of the great advantages of instrumental neutron-activation analysis is that it lends itself to automation.

It is envisaged that a throughput of 150 samples per man-day could be achieved in the best cases under the following conditions.

(1) A large number of samples is to be analysed for the same element or elements.

(2) The only sample preparation is the weighing of samples into polyethylene vials. This can be done at the rate of 300 per man-day.

(3) The samples are loaded into a rabbit, and the irradiation decay and counting are done under automatic control. The only human intervention required is to unload the rabbit, and this could also be eliminated with different irradiation facilities.

(4) The determination of the peak area, and the corrections for mass, dead time, and flux are done by a programmable calculator interfaced to the analyser. Such a system would be viable for a maximum of say 5 to 10 peaks per gamma spectrum.

(5) At the end of each analysis, the calculator prints out the concentrations of the elements, and the report of the results would be produced in that form.

TABLE 2

The elements determined

No.	Element	Samples in which determined	No. of samples
1	Al	1, 2, 3, 4, 5, 6, 7, 8, 9, 10, 11, 12, 13, 14, 15,	15
2	Mn	1, 2, 3, 4, 5, 6, 7, 8, 9, 10, 11, 12, 13, 14, 15	15
3	Na	1, 2, 3, 4, 5, 6, 7, 8, 9, 10, 11, 12, 14, 15	14
4	Cu	1, 2, 3, 4, 5, 6, 9, 10, 11, 12, 14	11
5	V	1, 2, 7, 8, 9, 10, 11, 13, 14	9
6	As	2, 3, 4, 5, 6, 8, 11, 12, 14	9
7	W	1, 2, 3, 5, 10, 11, 14, 15	8
8	Ag	2, 3, 4, 5, 6, 11	6
9	Fe	1, 5, 7, 8, 9, 14	6
10	La	1, 3, 7, 8, 14	5
11	In	2, 3, 4, 6, 8, 9	6
12	Sm	1, 4, 5, 8, 14	5
13	Sb	3, 4, 5, 6, 8	5
14	Zn	1, 2, 3, 4, 5	5
15	Au	5, 8, 11, 12	4
16	Cr	7, 8, 9, 10	4
17	Cl	2, 11, 12, 14	4
18	K	5, 8, 14, 15	4
19	Ir	3, 11, 12	3
20	Mg	1, 7, 10	3
21	Sc	1, 7, 8	3
22	Co	1, 3, 4	3
23	Mo	2, 5	2
24	Ni	11, 12	2
25	Ti	1, 14	2
26	Ta	3, 5	2
27	Pt	11, 12	2
28	Pd	11, 12	2
29	Rh	11, 12	2
30	Ru	11, 12	2
31	Se	11, 12	2
32	Sr	14	1
33	U	5	1
34	Y	5	1
35	Eu	1	1

5. CONCLUSION

This project has demonstrated that a number of elements of analytical importance can be determined routinely by instrumental neutron-activation analysis in samples of importance to the mineral-processing industry. Many of these determinations can be made with precisions in the region of 1 per cent, and with a sample throughput of between 50 and 150 samples a day.

6. REFERENCES

1. GIJBELS, R. Neutron activation analysis of ores and minerals. *Miner. Sci. Engng*, vol. 5, no. 4. 1973. p. 304.
2. FESQ, H.W., BIBBY, D.M., SELLSCHOP, J.P.F., and WATTERSON, J.I.W. The determination of trace-element impurities in natural diamonds by instrumental neutron activation analysis. *J. Radioanalyt. Chem.*, vol. 17, 1973, p. 135.

TABLE 3

Summary of results

No.	Sample analysed	Elements determined and precision ranges*				
		<1 %	1 to 5 %	5 to 10 %	10 to 20 %	>20 %
9	Ferrochromium	Cr, Fe, V, Cu	Mn, Al, Na, Co	In		
8	Ferrochromium (high Si)	Cr, Mn, V, Al, Na	Fe, Co, K, As		La, In	Sb, Sm, Sc, Ag
12	Matte-leach residue-(collection in NiS)	Au, Pd, Rh, Cu, Na, Ni	Pt, Ru, Ir, As, Mn, Se	Al	Cl	
11	Matte-leach residue	Au, Pd, Pt, Rh, Ir, Cu, Al	Ru, As, Mn, Na, W, Se, V	Os, Ag, Ni, Cl		
10	Platinum ore	Al, Mn, Na	Cu, W, Mg, V, Cr			
15	Pegmatite	Al, Mn, Na	W	K		
13	Manganese ore	Mn	Al		V	
14	Iron ore (Sishen)	Fe, Al, Mn, Na	V, W, K, La, Cu	As, Ti	Sm, Sr, Cl	
7	Chromite	Cr, Al, V, Mn	Fe, Na, Co	La, Sc, Mg		
6	Lead concentrate (high Zn)	Cu, Zn, As, Al, Mn, Sb	Na, La, Co, Fe, Sm, Ba	W	Ta, U, Cd, Y, Mo, Au, K, Ag	
3	Copper concentrate	Cu, As, Mn	Zn, Al, Sb, Ta, Na, In, Co, Ir	La, W	Ag	
1	Copper ore (Phalaborwa)	Cu, Al, Mn, Na	Zn, V, W, Fe Sm, Ti, Eu	La, Sc, Mg	Co	
4	Zinc concentrate	Zn, Cu, As, Mn, Co	Al, Cd, Sb, In, Na	Ag	Sm	
2	Copper ore (Tsumeb)	Cu, As	Al, V, Mn	Zn, Mo	Ag, W, Na, Cl, In	
5	Lead concentrate	Cu, Mn, Sb, In	Al, Na, As, Ag	Co		

*Coefficients of variation from counting statistics

3. RASMUSSEN, S.E., FESQ, H.W. Neutron activation analysis of samples from the Kimberley Reef conglomerate. Johannesburg, National Institute for Metallurgy, *Report no. 1563*. 1973.
4. GUINN, V.P. Potential uses of neutron activation analysis methods in NIM's routine sample analysis work. Johannesburg, National Institute for Metallurgy, *Technical Memorandum*, 1973. (Unpublished.)
5. RASMUSSEN, S.E., WATTERSON, J.I.W., and BIBBY, D.M. Routine reactor neutron activation analysis. Johannesburg, National Institute for Metallurgy, 1973. (Unpublished.)
6. YULE, H.P. *PROC. INTERN. CONF. MODERN TRENDS IN ACTIVATION ANALYSIS, Gaithersburg, Md., 1968. De Voe, J.R., ed.* Washington, National Bureau of Standards, 1969. vol. 2, p. 1155.

APPENDIX

DETAILED RESULTS OF THE ANALYSES

TABLE 1-1

Copper ore (Phalabor[illegible]a) 7/69
(approximate copper concentration 0,038 per cent)

Element	Isotope	Peak energy keV	Ti	Td	Tc s	Interference	Precision* %	Estimated no. of analyses per day
Cu	Cu-64	511,0	30 min	2 d	500	Na-24	<1†	50
	Cu-66	1039,0	10 s	2 min	500	Negligible	<15	50
Zn	Zn-65	1115,4	30 min	2 d	500	Negligible	<2†	50
Al	Al-28	1778,9	10 s	1 min	200	Negligible	<1	140
V	V-52	1434,4	10 s	1 min	200	Negligible	<2	140
Mn	Mn-56	846,9	10 s	2 h	150	Negligible	<1	150
Na	Na-24	1368,4	30 min	1 d	[illegible]	Negligible	<1†	50
W	W-187	685,7	30 min	2 [illegible]	500	Negligible	<5†	50
Fe	Fe-59	1098,6	30 min	2 d	500	Negligible	<5†	50
		1291,5	30 min	2 d	500	Negligible	<5†	50
Sm	Sm-153	103,2	30 min	2 d	500	Ta-182 etc.	<5†	50
Ti	Ti-51	320	10 s	1 min	500	Cr-51	<5	50
Eu	Eu-152m	121,8	30 min	1 d	500	Ba-131 etc.	<5†	50
	Eu-152	962	30 min	2 d	500	Tb-160 etc.	<5†	50
La	La-140	1595,4	30 min	1 d	500	Negligible	<10†	50
Sc	Sc-46	889,4	30 min	1 d	500	Negligible	<10†	50
Mg	Mg-27	1014,1	10 s	10 min	500	Negligible	<10	50
Co	Co-60m	1332,4	10 s	10 min	500	Negligible	<20	50
	Co-60	1173,1	30 min	2 d	500	Negligible	<20†	50

*Coefficients of variation from counting statistics
†Extrapolated results

TABLE 1-2

Copper ore (Tsumeb) 15/69
(approximate copper concentration 14,1 per cent)

Element	Isotope	Peak energy keV	Ti	Td	Tc s	Interference	Precision* %	Estimated no. of analyses per day
Cu	Cu-64	511,0	10 s	1 d	280	Negligible	<1	100
	Cu-66	1039,0	10 s	1 min	180	Negligible	<1	150
Zn	Zn-69m	438,7	30 min	1 d	500	Negligible	<15†	50
	Zn-65	1115,4	30 min	1 d	500	Negligible	<7†	50
As	As-76	559,2	10 s	1 d	350	Sb-122	<1	80
Al	Al-28	1778,9	10 s	1 min	200	Negligible	<3	140
V	V-52	1434,4	10 s	1 min	200	Negligible	<3	140
Mn	Mn-56	846,9	10 s	4 h	200	Negligible	<3	140
In	In-116m	417,0	10 s	10 min	500	Negligible	<20	50
Mo	Mo-99	372	10 s	1 d	500	Negligible	<10†	50
Cl	Cl-38	1642,0	10 s	20 min	500	Negligible	<20	50
Na	Na-24	1368,4	30 min	1 d	500	Negligible	<20†	50
W	[illegible]-187	685,7	30 min	1 d	500	Negligible	<20†	50
Ag	Ag-108	632,9	10 s	1 min	500	Negligible	<15	50

*Coefficients of variation from counting statistics
†Extrapolated results

TABLE I-3

Copper concentrate OPH 264-5
(approximate concentrations copper 20 per cent, zinc 4 per cent)

Element	Isotope	Peak energy keV	*Ti*	*Td*	*Tc* s	Interference	Precision* %	Estimated no. of analyses per day
Cu	Cu-66	1039,0	10 s	2 min	200	Negligible	<1	140
	Cu-64	511	10 s	1 d	200	Negligible	<1	140
Zn	Zn-69m	438,7	30 min	1 d	500	Negligible	<4†	50
	Zn-65	1115,4	30 min	1 d	500	Negligible	<2†	50
As	As-76	559,2	30 min	1 d	500	Check Sb-122	<1†	50
Al	Al-28	1778,9	10 s	2 min	200	Negligible	<2†	140
Mn	Mn-56	846,9	10 s	10 min	200	Negligible	<1	140
Sb	Sb-122	564,0	30 min	1 d	200	Check As-76	<2†	140
Ta	Ta-182	1221,4	30 min	1 d	200	Negligible	<2†	140
Na	Na-24	1368,4	30 min	1 d	200	Negligible	<2†	140
In	In-116m	417,0	10 s	30 min	300	Negligible	<2	100
Co	Co-60	1332,4	30 min	1 d	500	Negligible	<2†	50
		1173,2	30 min	1 d	500	Negligible	<2†	50
Ir	Ir-194	328,5	30 min	1 d	500	Negligible	<2†	50
La	La-140	1595,4	30 min	1 d	500	Negligible	<10†	50
W	W-187	685,7	30 min	1 d	500	Negligible	<10†	50
Ag	Ag-108	632,9	10 s	1 min	300	Negligible	<15	50

*Coefficients of variation from counting statistics
†Extrapolated results

TABLE I-4

Zinc concentrate OPH 264-7
(approximate concentrations zinc 51 per cent, copper 0,3 per cent)

Element	Isotope	Peak energy keV	*Ti*	*Td*	*Tc* s	Interference	Precision* %	Estimated no. of analyses per day
Zn	Zn-69m	438,7	30 min	1 d	500	Negligible	<1	50
	Zn-65	1115,4	30 min	1 d	300	Negligible	<1	80
Cu	Cu-66	1037,0	10 s	60 s	500	Negligible	<5	50
	Cu-64	511,0	30 min	1 d	500	Slight Na-24	<1	50
As	As-76	559,2	30 min	1 d	500	Slight Sb-122	<1	50
Al	Al-28	1778,9	10 s	60 s	200	Negligible	<2	140
Mn	Mn-56	1810,7	10 s	1 h	200	Negligible	<2	140
		846,9	10 s	1 h	150	Negligible	<1	150
Co	Co-60	1332,4	30 min	1 d	500	Negligible	<1	50
		1173,1	30 min	1 d	500	Negligible	<1,5	50
Cd	Cd-115	335,0	30 min	1 d	500	Negligible	<2	50
	Cd-115	527,7	30 min	1 d	500	Negligible	<5	50
Sb	Sb-122	564,0	30 min	1 d	500	Negligible	<5	50
In	In-116m	417,0	10 s	10 min	200	Negligible	<5	150
Na	Na-24	1368,4	30 min	1 d	500	Negligible	<2	50
Ag	Ag-108	632,9	10 s	5 min	500	Negligible	<10	50
Sm	Sm-153	103,2	30 min	1 d	500	Ta-182 etc.	<20	50

*Coefficients of variation from counting statistics

TABLE I-5

Lead concentrate (high Zn) OPH 258-7
(approximate concentrations copper 1,4 per cent, zinc 7,6 per cent)

Element	Isotope	Peak energy keV	*Ti*	*Td*	*Tc* s	Interference	Precision* %	Estimated no. of analyses per day
Cu	Cu-64	511,0	30 min	2 d	120	Negligible	<5	150
	Cu-66	1039,0	10 s	2 min	500	Negligible	<1	150
Zn	Zn-65	1115,4	30 min	2 d	500	Negligible	<1	50
	Zn-69m	438,7	30 min	2 d	500	Negligible	<3	50
As	As-76	559,2	30 min	2 d	500	Check Sb-122	<1	50
Al	Al-28	1778,9	10 s	1 min	200	Negligible	<1	140
Mn	Mn-56	846,9	10 s	1 min	150	Negligible	<1	150
Sb	Sb-122	564,0	30 min	2 d	400	Check As-76	<1	60
Na	Na-24	1368,4	30 min	2 d	500	Negligible	<2	50
La	La-140	1595,4	30 min	2 d	500	Negligible	<2	50
Co	Co-60	1332,4	30 min	2 d	500	Negligible	<2	50
Fe	Fe-59	1098	30 min	2 d	500	Negligible	<3	50
Sm	Sm-153	103,2	30 min	2 d	500	Ta-182, Np-239	<2	50
Ba	Ba-131	496,3	30 min	2 d	500	Cd-115	<3	50
W	W-187	685,7	30 min	2 d	500	Negligible	<10	50
Ta	Ta-182	1221,4	30 min	2 d	500	Negligible	<15	50
U	Np-239	277,5	30 min	2 d	500	Negligible	<15	50
Cd	Cd-115	527,7	30 min	2 d	500	Negligible	<15	50
Y	Y-190m	202,4	10 s	15 min	500	Negligible	<15	50
Mo	Mo-99	140,6	30 min	2 d	500	Negligible	<15	50
Au	Au-198	411,8	30 min	2 d	500	Negligible	<15	50
K	K-42	1524,7	30 min	2 d	500	Negligible	<15	50
Ag	Ag-110m	884,5	30 min	2 d	500	Negligible	<15	50

*Coefficients of variation from counting statistics

TABLE I-6

Lead concentrate OPH 260-8
(approximate concentrations copper 4,9 per cent, zinc 32 per cent)

Element	Isotope	Peak energy keV	*Ti*	*Td*	*Tc* s	Interference	Precision* %	Estimated no. of analyses per day
Cu	Cu-64	511,0	30 min	2 d	200	Negligible	<1	140
	Cu-66	1039,0	10 s	5 min	200	Negligible	<2	140
Zn	Zn-65	1115,4	30 min	2 d	500	Negligible	<2†	50
	Zn-69m	438,7	30 min	2 d	500	Negligible	<1†	50
Al	Al-28	1778,9	10 s	2 min	500	Negligible	<2	50
Mn	Mn-56	846,9	10 s	10 min	150	Negligible	<1	150
Na	Na-24	1368,4	30 min	1 d	500	Negligible	<2	50
Sb	Sb-122	564,0	30 min	2 d	500	As-76	<1†	50
In	In-116m	417,0	10 s	5 min	500	Negligible	<1	50
As	As-76	559,2	30 min	2 d	500	Negligible	<5†	50
Ag	Ag-108	632,9	10 s	1 min	500	Negligible	<5	50
Co	Co-60	1332,4	30 min	2 d	500	Negligible	<10†	50

*Coefficients of variation from counting statistics
†Extrapolated results

TABLE I-7

Chromite PH 783-6
(approximate concentrations chromium 34 per cent, iron 22 per cent)

Element	Isotope	Peak energy keV	Ti	Td	Tc s	Interference	Precision* %	Estimated no. of analyses per day
Cr	Cr-51	320,1	30 min	2 d	180	Negligible	<1	150
Al	Al-28	1778,9	10 s	2 min	150	Negligible	<1	150
V	V-52	1434,4	10 s	10 min	450	Negligible	<1	60
Mn	Mn-56	846,9	10 s	20 min	200	Negligible	<1	140
Fe	Fe-59	1098	30 min	2 d	500	Negligible	<3	50
		1292	30 min	2 d	500	Negligible	<3	50
Na	Na-24	1368,4	30 min	2 d	500	Negligible	<2	50
Co	Co-60	1332,4	30 min	2 d	500	Negligible	<3	50
La	La-140	1595,5	30 min	2 d	500	Negligible	<10	50
Sc	Sc-46	889,4	30 min	2 d	500	Negligible	<7	50
Mg	Mg-27	1014,1	10 s	10 min	500	Negligible	<10	50

*Coefficients of variation from counting statistics

TABLE I-8

Ferrochromium (high Si) PH 691-5
(approximate concentrations chromium 29 per cent, iron 27 per cent)

Element	Isotope	Peak energy keV	Ti	Td	Tc s	Interference	Precision* %	Estimated no. of analyses per day
Cr	Cr-51	320,1	30 min	2 d	200	Negligible	<1	140
Fe	Fe-59	1098	30 min	2 d	500	Negligible	<2	50
		1293	30 min	2 d	500	Negligible	<2	50
Mn	Mn-56	846,9	10 s	30 min	200	Negligible	<1	140
V	V-52	1434,4	10 s	5 min	150	Negligible	<1	150
Al	Al-28	1778,9	10 s	1 min	200	Negligible	<1	140
Co	Co-60	1332,4	30 min	2 d	500	Negligible	<2	50
Na	Na-24	1368,4	30 min	1 d	200	Negligible	<1	140
K	K-42	1524,7	30 min	1 d	500	Negligible	<4	50
As	As-76	559	30 min	2 d	500	Sb-122	<5	50
La	La-140	1595,5	30 min	2 d	500	Negligible	<15	50
In	In-116m	417,0	10 s	5 min	500	Negligible	<15	50
Sb	Sb-122	564,0	30 min	2 d	500	Negligible	<30	50
Sm	Sm-153	103,2	30 min	2 d	500	Check	<25	50
Sc	Sc-46	889,4	30 min	2 d	500	Check	<30	50
Au	Au-197	411,8	30 min	2 d	500	Check	<30	50

*Coefficients of variation from counting statistics

TABLE I-9

Ferrochromium OPH 798-1
(approximate concentrations chromium 47 per cent, iron 39 per cent)

Element	Isotope	Peak energy keV	*Ti*	*Td*	*Tc* s	Interference	Precision* %	Estimated no. of analyses per day
Cr	Cr-51	320,1	30 min	2 d	150	Negligible	<1†	150
Fe	Fe-59	1098	30 min	2 d	200	Negligible	<1†	140
		1293	30 min	2 d	200	Negligible	<1†	140
V	V-52	1434,4	10 s	5 min	200	Negligible	<1	140
Mn	Mn-56	846,9	10 s	30 min	500	Negligible	<2	50
Al	Al-28	1778,9	10 s	1 min	200	Negligible	<2	140
Cu	Cu-64	511,0	30 min	1 d	500	Na-24	<1†	50
In	In-116m	417,0	10 s	5 min	500	Negligible	<10	50
Na	Na-24	1368,4	30 min	1 d	500	Negligible	<5†	50
Co	Co-60	1332,4	30 min	2 d	500	Negligible	<5†	50

*Coefficients of variation from counting statistics
†Extrapolated results

TABLE I-10

Platinum ore PT 01

Element	Isotope	Peak energy keV	*Ti*	*Td*	*Tc* s	Interference	Precision* %	Estimated no. of analyses per day
Al	Al-28	1778,9	10 s	5 min	150	Negligible	<1	150
Mn	Mn-56	846,9	10 s	1 h	150	Negligible	<1	150
Na	Na-24	1368,4	30 min	1 d	200	Negligible	<1†	140
Cu	Cu-64	511,0	30 min	1 d	500	Na-24	<2†	50
	Cu-66	1039,0	10 s	10 min	500	Negligible	<20	50
W	W-187	685,7	30 min	1 d	500	Negligible	<2†	50
Mg	Mg-27	1014,1	10 s	10 min	500	Negligible	<5	50
V	V-52	1434,2	10 s	10 min	500	Negligible	<5	50
Cr	Cr-51	320,1	30 min	2 d	500	Negligible	<5†	50

*Coefficients of variation from counting statistics
†Extrapolated results

TABLE I-11

Matte-leach residue 22/72

Element	Isotope	Peak energy keV	Ti s	Td	Tc s	Interference	Precision* %	Estimated no. of analyses per day
Au	Au-197	411,8	10	30 min	200	Negligible	<1	140
Pd	Pd-109	188,9	10	10 min	500	Check	<1	50
Pt	Pt-199	542,8	10	30 min	500	Negligible	<1	50
		493,5	10	30 min	500	Negligible	<2	50
Rh	Rh-104	555,8	10	1 min	300	As-76	<1	50
Ru	Ru-105	469,6	10	30 min	500	As-76	<3	50
Ir	Ir-194	328,5	20	1 d	500	As-76	<2	50
	Ir-192	316,9	20	1 d	500	As-76	<1	50
Os	Os-185	645,8	20	1 d	500	Check	<10	50
Ag	Ag-110	658,0	10	1 min	500	Check	<10	50
	Ag-108	632,9	10	1 min	200	Negligible	<20	140
As	As-76	559,2	20	1 d	500	Negligible	<2	50
Mn	Mn-56	846,8	10	30 min	500	Negligible	<2	50
Na	Na-24	1368,4	20	1 h	500	Negligible	<2	50
Cu	Cu-64	511,0	20	1 d	500	Negligible	<1	50
	Cu-66	1039,0	10	10 min	500	Negligible	<1	50
Al	Al-28	1778,9	10	5 min	200	Negligible	<5	140
W	W-187	685,7	20	1 d	500	Negligible	<2	50
Se	Se-77m	161,9	20	1 min	500	Negligible	<5	50
Ni	Ni-65	1481,7	20	30 min	500	Negligible	<10	50
V	V-52	1434,2	10	10 min	500	Negligible	<5	50
Cl	Cl-38	1642,0	20	30 min	500	Negligible	<10	50

*Coefficients of variation from counting statistics

TABLE I-12

Matte-leach residue (NiS collection) FF 88

Element	Isotope	Peak energy keV	Ti	Td	Tc s	Interference	Precision* %	Estimated no. of analyses per day
Au	Au-198	411,8	10 s	30 min	200	Negligible	<1	140
Pd	Pd-109m	188,9	20 s	10 min	500	Check	<1	50
Pt	Pt-199	542,8	20 s	30 min	500	Negligible	<2	50
		493,5	20 s	30 min	500	Negligible	<3	50
	Au-199	158,4	30 min	1 d	500	Negligible	<4†	50
Rh	Rh-104	555,8	20 s	1 min	500	Check As-76	<1	50
Ru	Ru-105	469,6	20 s	30 min	500	Negligible	<5	50
Ir	Ir-194	328,5	30 min	1 d	500	Negligible	<3†	50
	Ir-192	316,5	30 min	1 d	500	Negligible	<2†	50
Cu	Cu-64	511,0	30 min	1 d	300	Negligible	<1†	130
As	As-76	559,2	30 min	1 d	500	Negligible	<3	50
Mn	Mn-56	846,9	20 s	30 min	500	Negligible	<2	50
Na	Na-24	1368,4	30 min	1 d	200	Negligible	<1†	140
Ni	Ni-65	1481,7	20 s	30 min	200	Negligible	<1	140
Se	Se-77m	161,9	10 s	1 min	200	Check	<4	140
Al	Al-28	1778,9	10 s	5 min	500	Negligible	<10	50
Cl	Cl-38	1642,0	20 s	30 min	500	Negligible	<20	50

*Coefficients of variation from counting statistics
†Extrapolated results

TABLE I-13

Manganese ore 21/67

Element	Isotope	Peak energy keV	*Ti* s	*Td*	*Tc* s	Interference	Precision* %	Estimated no. of analyses per day
Mn	Mn-56	846,9	10	5 min	130	Negligible	<1	>150
Al	Al-28	1778,9	10	1 min	500	Negligible	<2	50
V	V-52	1434,4	10	1 min	500	Negligible	<2	50

*Coefficients of variation from counting statistics

TABLE I-14

Iron ore (Sisben) SS06/C
(Approximate concentrations iron 60 to 70 per cent,
Al_2O_3 0,5 to 2 per cent, manganese 0,03 to 0,05 per cent)

Element	Isotope	Peak energy keV	*Ti*	*Td*	*Tc* s	Interference	Precision* %	Estimated no. of analyses per day
Fe	Fe-59	1293,6	30 min	2 d	500	Negligible	<1	50
		1099	30 min	2 d	500	Negligible	<2	50
Al	Al-28	1778,9	10 s	1 min	150	Negligible	<1	50
Mn	Mn-56	846,9	10 s	1 h	500	Negligible	<1	50
Na	Na-24	1368,4	30 min	1 d	500	Negligible	<1	50
V	V-52	1434,4	10 s	10 min	500	Negligible	<3	50
W	W-187	685,7	30 min	2 d	500	Negligible	<5	50
K	K-42	1524,7	30 min	1 d	500	Negligible	<5	50
La	La-140	1595,4	30 min	2 d	500	Negligible	<5	50
Cu	Cu-64	511,0	30 min	1 d	500	Negligible	<5	50
As	As-76	559,2	30 min	1 d	500	Negligible	<10	50
Sm	Sm-153	103,2	30 min	1 d	500	Negligible	<15	50
Ti	Ti-51	320,0	10 s	10 min	500	Negligible	<10	50
Sr	Sr-87m	388,5	20 s	1 h	500	Negligible	<15	50
Cl	Cl-38	1642,0	20 s	1 h	500	Negligible	<20	50

*Coefficients of variation from counting statistics

TABLE I-15

Pegmatite

Element	Isotope	Peak energy keV	*Ti*	*Td*	*Tc* s	Interference	Precision* %	Estimated no. of analyses per day
Al	Al-28	1778,9	10 s	1 min	150	Negligible	<1	150
Mn	Mn-56	846,9	10 s	1 h	150	Negligible	<1	150
Na	Na-24	1368,4	10 s	1 h	200	Negligible	<1	140
W	W-187	685,7	30 min	1 d	500	Negligible	<2	50
K	K-42	1524,7	30 min	1 d	500	Negligible	<10	50

*Coefficients of variation from counting statistics

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