X-RAY FLUORESCENCE ON-LINE ANALYSIS OF LEAD-ZINC ORE FRACTIONS IN MINERAL SLURRIES – A COMPARISON OF WAVELENGTH-DISPERSIVE AND ENERGY-DISPERSIVE TECHNIQUES

S.K. Kawatra and J.L. Dalton

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by

S.K. KAWATRA* and J.L. DALTON**

ABSTRACT

The work reported herein is part of a series of on-line X-ray fluorescence analysis studies dealing with copper-zinc ore, iron ore, and coal. Wavelength-dispersive and energy-dispersive X-ray fluorescence analysis techniques were simultaneously compared, using a slurry recirculation system consisting of a gamma-ray density gauge and flow cells attached to an X-ray tube excitation-wavelength dispersive system, and an isotope-excitation-energy dispersive system.

In both cases, the composition of the solids in complex lead-zinc ore slurries was determined as a function of the iron, zinc, lead, and scatter X-ray intensities, and the density gauge intensity, using multiple linear regression techniques. It was found that the energy dispersive system which is less expensive than a wavelength dispersive system, gives acceptable results for mill control purposes.

*National Research Council Post-Doctorate Fellow.

**Group Leader, X-Ray Fluorescence Analysis Group, Spectrochemistry Section, Laboratory for Chemical Analysis, Mineral Sciences Laboratories, Canada Centre for Mineral and Energy Technology, Department of Energy, Mines and Resources, Ottawa, Canada.

L'ANALYSE EN LIGNE DIRECTE PAR FLUORESCENCE DES RAYONS X
DES FRACTIONS D'UN MINERAI DE PLOMB ET DE ZINC
CONTENUES DANS DES BOUES MINERALES; UNE ETUDE COMPARATIVE
ENTRE LES TECHNIQUES DE DISPERSION DE LA LONGUEUR
D'ONDE ET CELLES DE DISPERSION DE L'ENERGIE

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SOMMAIRE

Le présent rapport fait partie d'une série d'études entre-
prises sur l'analyse en ligne directe par fluorescence des rayons
X des minerais de cuivre et de zinc, de fer ainsi que du charbon.
L'étude, dont on parle ici, a porté sur la comparaison simultanée
des techniques d'analyse par fluorescence des rayons X de la dis-
persion de la longueur d'onde et de la dispersion de l'énergie, à
l'aide d'un système de recirculation de la boue, dont une jauge
de densité des rayons gamma et des cellules d'écoulement sont at-
tachées à un système de dispersion de la longueur d'onde d'un tube
d'excitation des rayons X, ainsi qu'à un système de dispersion de
l'énergie d'excitation des isotopes.

Dans les deux cas, la composition des solides compris dans
les boues complexes de plomb et de zinc a été déterminée en fonc-
tion du fer, du zinc, du plomb et des intensités dispersées des
rayons X et en fonction de l'intensité de la jauge de densité, à
l'aide de méthodes de régression linéaire multiples. On a consta-
té que le système de dispersion de l'énergie, qui s'avère être le
moins coûteux des deux systèmes, donne des résultats acceptables
pour un contrôle en usine.

*Boursier post-doctoral du Conseil national de recherches.
**Chef du groupe de l'analyse par fluorescence des rayons X, Section
  de la spectrochimie, Laboratoire de l'analyse chimique, Laboratoires
  des sciences minérales, CANMET, Ministère de l'Energie, des Mines
  et des Ressources, Ottawa, Canada.

INTRODUCTION

The information in this report was gathered as part of the Minerals Research Program, P-1 Activity. The objective of the program is to ensure the efficient extraction and utilization of Canada's minerals, and that of the activity is to study the extractive metallurgy of the lead-zinc ores of Eastern Canada. On-line X-ray fluorescence analysis is used in mineral beneficiation plants as process control instrumentation to monitor the solids composition at various stages in the beneficiation process. The substance of this report supports the aim of the program by comparing the merits of two techniques of X-ray fluorescence analysis used in process control.

BACKGROUND

X-ray fluorescence analysis (XRFA) has been used for on-line compositional analysis in the mineral industry for several years (1,2,3,4,5,6,7). The most popular, and the most expensive instrumentation possesses multi-stream multi-element capabilities. Slurry samples, taken from various points in the mineral concentrator, are pumped to an air-conditioned control room, in which a wavelength-dispersive spectrometer is located. This spectrometer generally has an X-ray tube for excitation, a curved analyzing crystal for simultaneous measurements, and several detectors. Depending upon the manufacturer, each slurry stream may be analyzed for as many as eight elements, and up to 14 streams may be analyzed by one spectrometer.

A great deal of work has been carried out in Australia on radioisotope excitation and immersible probes for on-line analysis (3,4) to reduce the cost of XRFA in mineral concentators. The probe is designed for immersion into the slurry circuit in the flotation cells. It contains a radioisotope source and an X-ray detector, thus eliminating the need for slurry sampling, pumping equipment, X-ray generator, and tube. This type of XRFA instrumentation has not gained acceptance in Canada, perhaps because each probe is capable of determining only a single element. The use of an energy-dispersive detector (EDX), such as the Si(Li) X-ray detector, with radioisotope excitation appears to be an attractive proposition for on-line XRFA, but has not received any attention in the scientific literature. The

technique has been in use for analyzing discrete samples for some time (8), and Inax Instruments of Ottawa manufactures both discrete and on-line analyzers employing this technique (9).

The type of instrumentation used in on-line XRFA is adequately described in references 1 to 7. For the relation of chemical composition of the mineral product to X-ray fluorescence intensities, Kay uses linear regression techniques, with inter-element and density effect considerations at Inco's Clarabelle mill (6), so also Gowans uses linear programming at the Sullivan concentrator of Cominco (2). Smith emphasizes that calibration requires carefully controlled experiments and the application of relatively sophisticated mathematical techniques (7).

Two areas of on-line XRFA where an investigation would therefore be of value to the mineral industry were (i) the use of an energy-dispersive x-ray detector with radioisotope excitation, and (ii) the mathematical relationship between x-ray fluorescence intensities and chemical composition.

Accordingly, a test rig was assembled which included both wavelength-dispersive and energy-dispersive instrumentation, so that a comparison could be made between the two techniques of XRFA on the same slurry. The material chosen was lead-zinc ore fractions from British Columbia and New Brunswick forming part of the P-1 Processing Activity of the Minerals Research Project. The composition of the ore fractions is given in Table 1.

EXPERIMENTAL

A schematic diagram of the test rig is shown in Fig. 1. It consisted of a three-litre receiving tank, a variable-speed peristaltic recirculating pump (Peri Manufacturing Co., Model 240-B, Trenton, Ont.), a density gauge assembly, a constant-flow head tank, a single-window flow cell in an assembly with isotope-excitation and an Si(Li) x-ray detector, and a single-window flow cell mounted to a modified Philips model 1540 x-ray spectrometer. Details of the density gauge and the two single-window flow cell assemblies are listed in Table 2.

The 10-mCi Co-60 point-source isotope was placed in a brass fitting underneath the lead plates forming the base of the density gauge assembly. Radiation collimation was accomplished by a 0.95-cm diameter aperture in the 10-cm thick lead base.

A schematic diagram of the single window flow-cell in the isotope-excitation assembly is shown in Fig. 2. Two radio-isotopes were used in the EDX assembly - Gd-153 and Am-241 - so that a comparison could be made of their suitability. The characteristics of these sources are detailed in Table 3. A schematic of the Philips 1540 x-ray spectrometer, modified to accept a slurry flow cell in a vertical alignment, is shown in Fig. 3.

The experimental strategy was to prepare aqueous mineral slurries that simulated concentrator practice as far as practicable. Changes in solids composition were achieved by adding varying quantities of dry concentrate and tailings to

slurries simulating feed and tailings lines, reagent grade
chemicals and feed to a concentrate line, and pyrite and feed
to a tailing line.

The experimental procedure was to add three litres of
water to the circuit, start the peristaltic pump, and record the
water measurements. Various quantities of ore fractions were
then added, allowed to mix until a homogeneous slurry had been
achieved, and the measurements then recorded. A typical slurry
run consisted of approximately 20 ore additions and required
eight to ten hours.

The X-ray measurements taken with the Philips spectro-
meter were for the Pb L_α, Zn K_α, W L_α, and Fe K_α radiation, and
with the EDX system for Pb L_α, Pb L_β, Zn K_α, Fe K_α, and Compton
and Rayleigh scatter radiation from the particular isotope. No
attempt was made to obtain net intensities, by the use of a
background correction, because background is not normally
measured in on-line XRFA systems.

RESULTS AND DISCUSSION

The data analysis consisted of a multiple linear
regression on the experimental intensities. The mathematical
model chosen for study was as follows;
Percentage of Element In Solids =

$$K_0 + K_1 I_{Pb} + K_2 I_{Zn} + K_3 I_{Fe} + K_4 I_{Sc} + K_5 I_{Pd} \qquad (1)$$

where K_0 to K_5 are calibration constants determined by mathema-
tical analysis; I_{Pb}, I_{Zn}, I_{Fe}, and I_{Sc} are the x-ray intensities

from lead, zinc, iron, and scatter radiations, respectively, and I_{Pd} is the transmitted gamma-ray intensity from the density gauge.

The data analysis for the Philips spectrometer was straight-forward insofar as there were no changes from one run to another. Lead, zinc, and iron were always determined as a function of the intensities of Pb L_α, Zn K_α, Fe K_α, W L_α-Rayleigh Scatter, and the density gauge. However the EDX system was more complicated as two isotopes were used, both Rayleigh and Compton scatter measurements were taken, and both lead L_α and L_β radiations were measured. Thus, calibration constants were determined four times for each of lead, zinc and iron. The equations used are shown in Table 4. The results of the data analysis as well as the pertinent solids compositional data applying to the particular slurry are shown in Tables 5-14 inclusive.

A study of the tables show that the data processing technique is acceptable for on-line analysis, as most of the percentage error is less than five per cent, although the lead and zinc determinations in the two tailings runs, with the Gd-153 isotope, are quite high. It is not apparent why this should be so high and it does not appear reasonable that the Gd-153 isotope is not as good as the Am-241, as most of the mathematically determined errors for the two isotopes are almost the same. It is to be noted that the lead L_β line shows consistently better accuracy than the lead L_α, and the Compton scatter provides a better correction factor than the Rayleigh. A further analysis of the tables shows that the wavelength-dispersive technique employing an x-ray tube with a crystal gives better

precision than the energy-dispersive technique employing an iso-
tope and a solid state detector. However it may be reiterated
that the energy-dispersive technique gives the desired precision
for control of mineral processing operations. Moreover in a
plant the precision is restricted not by the technique but by the
variation of plant parameters such as particle size (11) and
entrained air in mineral slurries (12).

The energy-dispersive system described is more porta-
ble than the wavelength-dispersive system. It is thus possible
to take the analyzer to a flowing stream rather than the pulp
stream to the sampler. A wavelength-dispersive system, on the
other hand, is not only bulky and expensive but requires a cen-
tral control room necessitating the use of long sampling lines,
which add to the cost of the system. Therefore the use of a
wavelength-dispersive system for assay or process control work
cannot always be justified.

CONCLUSIONS

An energy-dispersive system employing an isotope gives
the desired precision for control of a mineral processing plant
and is more economical than a wavelength-dispersive system. It
is then acceptable for a mineral processing operation.

ACKNOWLEDGEMENT

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TABLE 1

Analysis of Lead-Zinc Ore Products

Sample	% Moisture	% Lead	% Zinc	% Iron	% Sulphur
75-1423 Brunswick Head	0.12	3.66,3.72 / 3.69	9.31, 9.31 / 9.31	29.05,29.05,29.01 / 29.04	35.14,34.91,35.26 / 35.10
75-1424 Brunswick Pb Conc.	0.15	36.23,36.40 / 36.32	5.96, 5.97 / 5.97	21.41,21.39,21.65 / 21.48	31.56,31.61,31.68 / 31.62
75-1425 Brunswick Comb. Tail	0.11	1.01, 1.01 / 1.01	1.89, 1.87 / 1.88	34.12,34.17,34.26 / 34.18	37.56,37.34,37.44 / 37.45
75-1426 Brunswick Zn Conc.	0.24	1.50, 1.50 / 1.50	51.56,51.76 / 51.66	9.00, 8.98, 9.03 / 9.00	30.61,30.70,30.27 / 30.53
75-1427 Cominco Zn Conc.	0.26	5.98, 6.09 / 6.04	48.33,48.20 / 48.27	10.78,10.82,10.92 / 10.84	30.16,30.19,29.54 / 29.96
75-1428 Cominco Pb Conc.	<0.02	65.75,65.90 / 65.83	4.01, 4.03 / 4.02	8.99, 8.91, 9.08 / 8.99	17.60,17.45,17.64 / 17.56
75-1429 Cominco Zn Ro. Conc.	1.05	1.83, 1.85 / 1.84	10.20,10.20 / 10.20	33.34,33.21,33.22 / 33.26	24.64,24.57,24.87 / 24.69
75-1430 Cominco Tail	1.01	0.47, 0.45 / 0.46	0.42, 0.42 / 0.42	34.77,34.43,34.56 / 34.59	20.48,20.43,20.65 / 20.52
75-1431 Cominco Feed	0.02	6.77, 6.85 / 6.81	6.75, 6.80 / 6.77	23.32,23.30,23.27 / 23.30	17.97,17.52,17.68 / 17.72

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TABLE 2

Details of Analytical Instrumentation

1. Density gauge

Radiation path length through slurry	-20 cm
Isotope	-10 mCi Co-60 point source (AECL)
Detector	-2 in x 2 in NaI (Tl) (Harshaw)
High voltage supply	-Ortec Model 456
Analyzer	-Baird-Atomic Model 530
Discriminator settings	-Lower Level, 1.0 MeV -Upper Level, Threshold

2. Single window flow cell with isotope excitation and energy analysis
    system

X-ray window	-3 mil polypropylene, 3.2 cm in diameter
Excitation	-1) 100 mCi Am-241 annular source (Inax Instruments) -2) 100 mCi Gd-153 annular source (Inax Instruments)
Collimation	-Inax Instruments dual assembly, sample aperture 1.6 cm detector aperture .33 cm material - pure tin
Detection	-Si(Li) x-ray detector, active diameter 6 mm, depth 3 mm, Ortec Model 7116-06215
High voltage supply	-Ortec Model 456
Amplifier	-Ortec Model 730
Analyzer	-Tracor-Northern TN-1700 Pulse Height Analyzer

3. Single window flow cell with X-ray tube excitation and wavelength
    analysis system

X-ray window	-3 mil polypropylene, 3.2 cm in diameter
Spectrometer	-Modified Philips 1540 X-ray spectrometer fitted with a Philips NR-100 tungsten target x-ray tube
Analyzing crystal	-LiF (220)
Detection	-Philips PW 1964 Scintillation Detector
High voltage supply	-Philips PW 4025
Electronics	-Philips single channel analyzer -PW 1365 Pulse shaper -PW 4280 Amplifier/Analyzer -PW 4231 Scaler -PW 4261 Timer

TABLE 3

Characteristics of Radioisotopes Used in Study (ref. 10)

Isotope	Half-Life	Gamma Radiation (keV)
EDX system		
Am-241	458 years	13.945
		17.740
		20.774
		60.0
		small amounts of radiation in the range 100-700
Gd-153	240 days	41.5
		47.0
		70.0
		99.0 (complex)
Density gauge		
Co-60	5.2 years	1,173
		1,332

Table 4:   Mathematical Equations for on-line
           analysis of lead and zinc ore
           fractions.

High voltage x-ray excitation:

$$\% \text{ Pb} = K0 + K1 \cdot I_{PbL\beta} + K2 \cdot I_{ZnK\alpha} + K3 \cdot I_{WL\alpha} + K4 \cdot I_{FeK\alpha} + K5 \cdot I_{Pd} \qquad (1)$$

$$\% \text{ Zn} = K6 + K7 \cdot I_{PbL\beta} + K8 \cdot I_{ZnK\alpha} + K9 \cdot I_{WL\alpha} + K10 \cdot I_{FeK\alpha} + K11 \cdot I_{Pd} \qquad (2)$$

$$\% \text{ Fe} = K12 + K13 \cdot I_{PbL\beta} + K14 \cdot I_{ZnK\alpha} + K15 \cdot I_{WL\alpha} + K16 \cdot I_{FeK\alpha} + K17 \cdot I_{Pd} \qquad (3)$$

Isotope excitation:

Per cent Lead

$$\% \text{ Pb} = K18 + K19 \cdot I_{FeK\alpha} + K20 \cdot I_{ZnK\alpha} + K21 \cdot I_{PbL\alpha} + K22 \cdot I_{Compton} + K23 \cdot I_{Pd} \qquad (4)$$

$$\% \text{ Pb} = K24 + K25 \cdot I_{FeK\alpha} + K26 \cdot I_{ZnK\alpha} + K27 \cdot I_{PbL\alpha} + K28 \cdot I_{Rayleigh} + K29 \cdot I_{Pd} \qquad (5)$$

$$\% \text{ Pb} = K30 + K31 \cdot I_{FeK\alpha} + K32 \cdot I_{ZnK\alpha} + K33 \cdot I_{PbL\beta} + K34 \cdot I_{Compton} + K35 \cdot I_{Pd} \qquad (6)$$

$$\% \text{ Pb} = K36 + K37 \cdot I_{FeK\alpha} + K38 \cdot I_{ZnK\alpha} + K39 \cdot I_{PbL\beta} + K40 \cdot I_{Rayleigh} + K41 \cdot I_{Pd} \qquad (7)$$

Per cent Zinc

$$\% \text{ Zn} = K42 + K43 \cdot I_{FeK\alpha} + K44 \cdot I_{ZnK\alpha} + K45 \cdot I_{PbL\alpha} + K46 \cdot I_{Compton} + K47 \cdot I_{Pd} \qquad (8)$$

$$\% \text{ Zn} = K48 + K49 \cdot I_{FeK\alpha} + K50 \cdot I_{ZnK\alpha} + K51 \cdot I_{PbL\alpha} + K52 \cdot I_{Rayleigh} + K53 \cdot I_{Pd} \qquad (9)$$

$$\% \text{ Zn} = K54 + K55 \cdot I_{FeK\alpha} + K56 \cdot I_{ZnK\alpha} + K57 \cdot I_{PbL\beta} + K58 \cdot I_{Compton} + K59 \cdot I_{Pd} \qquad (10)$$

$$\% \text{ Zn} = K60 + K61 \cdot I_{FeK\alpha} + K62 \cdot I_{ZnK\alpha} + K63 \cdot I_{PbL\beta} + K64 \cdot I_{Rayleigh} + K65 \cdot I_{Pd} \qquad (11)$$

Per cent Iron

$$\% \text{ Fe} = K66 + K67 \cdot I_{FeK\alpha} + K68 \cdot I_{ZnK\alpha} + K69 \cdot I_{PbL\alpha} + K70 \cdot I_{Compton} + K71 \cdot I_{Pd} \qquad (12)$$

$$\% \text{ Fe} = K72 + K73 \cdot I_{FeK\alpha} + K74 \cdot I_{ZnK\alpha} + K75 \cdot I_{PbL\alpha} + K76 \cdot I_{Rayleigh} + K77 \cdot I_{Pd} \qquad (13)$$

$$\% \text{ Fe} = K78 + K79 \cdot I_{FeK\alpha} + K80 \cdot I_{ZnK\alpha} + K81 \cdot I_{PbL\beta} + K82 \cdot I_{Compton} + K83 \cdot I_{Pd} \qquad (14)$$

$$\% \text{ Fe} = K84 + K85 \cdot I_{FeK\alpha} + K86 \cdot I_{ZnK\alpha} + K87 \cdot I_{PbL\beta} + K88 \cdot I_{Rayleigh} + K89 \cdot I_{Pd} \qquad (15)$$

where $I_{FeK\alpha}$, $I_{ZnK\alpha}$, $I_{PbL\alpha}$, $I_{PbL\beta}$, $I_{WL\alpha}$, $I_{Compton}$, $I_{Rayleigh}$, I_{Pb} are counts corresponding to Fe K_α, Zn K_α, Pb L_α, Pb L_α, IWL$_\alpha$, Compton, Rayleigh x-rays and pulp density of mineral slurry and K0-K89 are calibration constants.

Table 5:   Precision of determining lead, zinc and iron in
feed samples from Cominco Ltd.

Analysis for	Per cent by weight		Mode of excitation	Mathematical equation used	Error	Per cent Error
	Range	Mean				
Lead	3.98-6.91	5.33	HV Xray	1	0.095	1.77
			Am-241	4	0.173	3.25
			Am-241	5	0.189	3.53
			Am-241	6	0.113	2.11
			Am-241	7	0.154	2.88
Zinc	5.18-6.77	5.98	HV Xray	2	0.062	1.05
			Am-241	8	0.092	1.54
			Am-241	9	0.092	1.54
			Am-241	10	0.094	1.56
			Am-241	11	0.094	1.58
Iron	23.3-28.61	27.14	HV Xray	3	0.093	0.34
			Am-241	12	0.286	1.05
			Am-241	13	0.286	1.05
			Am-241	14	0.263	0.970
			Am-241	15	0.263	0.969

Table 6:   Precision of determining lead, zinc and iron in
concentrate samples from Cominco Ltd.

Analysis for	Per cent by weight		Mode of excitation	Mathematical equation used	Error	Per cent Error
	Range	Mean				
Lead	44.0-65.8	51.8	HV Xray	1	0.42	0.81
			Am-241	4	0.56	1.09
			Am-241	5	0.54	1.05
			Am-241	6	0.47	0.92
			Am-241	7	0.46	0.89
Zinc	4.0-11.0	8.13	HV Xray	2	0.32	3.98
			Am-241	8	0.45	5.52
			Am-241	9	0.44	5.43
			Am-241	10	0.41	5.08
			Am-241	11	0.40	4.98
Iron	9.0-13.0	11.76	HV-Xray	3	0.19	1.60
			Am-241	12	0.29	2.47
			Am-241	13	0.29	2.47
			Am-241	14	0.29	2.48
			Am-241	15	0.29	2.48

Table 7: Precision of determining lead, zinc and iron in tailing samples from Cominco Ltd.

Analysis for	Per cent by weight		Mode of excitation	Mathematical equation used	Error	Per cent Error
	Range	Mean				
Lead	0.46-1.43	0.93	HV Xray	1	0.022	2.37
			Am-241	4	0.053	5.70
			Am-241	5	0.053	5.72
			Am-241	6	0.052	5.63
			Am-241	7	0.051	5.55
Zinc	0.43-1.54	0.98	HV Xray	2	0.016	1.61
			Am-241	8	0.055	5.59
			Am-241	9	0.055	5.62
			Am-241	10	0.054	5.47
			Am-241	11	0.053	5.41
Iron	32.89-37.38	34.78	HV Xray	3	0.205	0.59
			Am-241	12	0.265	0.76
			Am-241	13	0.259	0.74
			Am-241	14	0.266	0.76
			Am-241	15	0.265	0.76

Table 8: Precision of determining lead, zinc and iron in feed samples from Cominco Ltd.

Analysis for	Per cent by weight		Mode of excitation	Mathematical equation used	Error	Per cent Error
	Range	Mean				
Lead	3.98-6.90	5.80	HV Xray	1	0.116	2.0
			Gd-153	4	0.171	2.94
			Gd-153	5	0.174	3.00
			Gd-153	6	0.163	2.83
			Gd-153	7	0.168	2.91
Zinc	5.18-6.93	6.24	HV Xray	2	0.064	1.04
			Gd-153	8	0.158	2.54
			Gd-153	9	0.131	2.11
			Gd-153	10	-	-
			Gd-153	11	-	-
Iron	23.3-28.61	27.08	HV Xray	3	0.153	0.57
			Gd-153	12	0.24	0.91
			Gd-153	13	0.30	1.14
			Gd-153	14	-	-
			Gd-153	15	-	-

Table 9: Precision of determining lead, zinc and iron in concentrate samples from Cominco Ltd.

Analysis for	Per cent by weight		Mode of excitation	Mathematical equation used	Error	Per cent Error
	Range	Mean				
Lead	40.25-65.83	49.63	HV Xray	1	0.94	1.90
			Gd-153	4	1.01	2.04
			Gd-153	5	0.84	1.68
			Gd-153	6	1.02	2.05
			Gd-153	7	1.92	3.88
Zinc	4.02-11.78	8.36	HV Xray	2	0.39	4.66
			Gd-153	8	0.42	5.05
			Gd-153	9	0.45	5.40
			Gd-153	10	-	-
			Gd-153	11	-	-
Iron	8.99-12.69	11.72	HV Xray	3	0.19	1.61
			Gd-153	12	0.49	4.21
			Gd-153	13	0.56	4.77
			Gd-153	14	-	-
			Gd-153	15	-	-

Table 10: Precision of determining lead, zinc and iron in concentrate samples from Cominco Ltd.

Analysis for	Per cent by weight		Mode of excitation	Mathematical equation used	Error	Per cent Error
	Range	Mean				
Lead	44.26-65.83	52.08	HV Xray	1	0.31	0.60
			Gd-153	4	0.82	1.57
			Gd-153	5	1.01	1.94
			Gd-153	6	0.40	0.76
			Gd-153	7	0.79	1.51
Zinc	4.02-11.79	8.10	HV Xray	2	0.11	1.31
			Gd-153	8	0.21	2.58
			Gd-153	9	0.22	2.68
			Gd-153	10	0.22	2.77
			Gd-153	11	0.22	2.74
Iron	8.99-12.69	11.73	HV Xray	3	0.17	1.43
			Gd-153	12	0.29	2.49
			Gd-153	13	0.33	2.85
			Gd-153	14	0.21	1.75
			Gd-153	15	0.30	2.51

Table 11: Precision of determining lead, zinc and iron
in tailing samples from Cominco Ltd.

Analysis for	Per cent by weight		Mode of excitation	Mathematical equation used	Error	Per cent Error
	Range	Mean				
Lead	0.46-0.86	0.70	HV Xray	1	0.025	3.58
			Gd-153	4	0.076	10.77
			Gd-153	5	0.072	10.29
			Gd-153	6	0.07	8.83
			Gd-153	7	0.06	8.81
Zinc	0.42-1.31	0.90	HV Xray	2	0.019	2.09
			Gd-153	8	0.115	12.77
			Gd-153	9	.119	13.19
			Gd-153	10	0.105	11.56
			Gd-153	11	0.115	12.68
Iron	33.95-37.69	35.33	HV Xray	3	0.11	0.31
			Gd-153	12	0.319	0.904
			Gd-153	13	0.288	0.82
			Gd-153	14	0.308	0.872
			Gd-153	15	0.289	0.82

Table 12: Precision of determining lead, zinc and iron in
tailing samples from Brunswick Mining and
Smelting Corp. Ltd.

Analysis for	Per cent by weight		Mode of excitation	Mathematical equation used	Error	Per cent Error
	Range	Mean				
Lead	1.01-1.63	1.32	HV Xray	1	0.026	1.99
			Gd-153	4	0.10	7.76
			Gd-153	5	0.099	7.50
			Gd-153	6	0.92	7.07
			Gd-153	7	0.084	6.45
Zinc	1.88-5.19	2.98	HV Xray	2	0.094	2.93
			Gd-153	8	0.20	6.45
			Gd-153	9	0.20	6.55
			Gd-153	10	0.21	6.74
			Gd-153	11	0.18	5.76
Iron	32.81-37.10	34.52	HV Xray	3	0.24	0.71
			Gd-153	12	0.33	0.94
			Gd-153	13	0.32	0.92
			Gd-153	14	0.32	0.91
			Gd-153	15	0.32	0.94

Table 13: Precision of determining lead, zinc and iron
in feed samples from Brunswick Mining and
Smelting Corp. Ltd.

Analysis for	Per cent by weight		Mode of excitation	Mathematical equation used	Error	Per cent Error
	Range	Mean				
Lead	2.51-4.92	3.53	HV Xray	1	0.06	1.84
			Gd-153	4	0.19	5.26
			Gd-153	5	0.19	5.29
			Gd-153	6	0.07	2.00
			Gd-153	7	0.09	2.50
Zinc	7.45-12.36	9.8	HV Xray	2	0.12	1.27
			Gd-153	8	0.16	1.62
			Gd-153	9	0.16	1.62
			Gd-153	10	0.16	1.63
			Gd-153	11	0.16	1.63
Iron	28.42-30.33	29.02	HV Xray	3	0.08	0.29
			Gd-153	12	0.12	0.42
			Gd-153	13	0.12	0.42
			Gd-153	14	0.09	0.31
			Gd-153	15	0.09	0.33

Table 14: Precision of determining lead, zinc and iron
in concentrate samples from Brunswick Mining
and Smelting Corp. Ltd.

Analysis for	Per cent by weight		Mode of excitation	Mathematical equation used	Error	Per cent Error
	Range	Mean				
Lead	29.07-36.32	32.79	HV X-ray	1	0.45	1.37
			Gd-153	4	1.16	3.54
			Gd-153	5	1.02	3.10
			Gd-153	6	1.02	3.11
			Gd-153	7	0.88	2.69
Zinc	5.75-6.27	6.07	HV Xray	2	0.086	1.41
			Gd-153	8	0.11	1.80
			Gd-153	9	0.11	1.80
			Gd-153	10	0.11	1.80
			Gd-153	11	0.11	1.80
Iron	20.31-23.51	22.30	HV Xray	3	0.07	0.32
			Gd-153	12	0.40	1.76
			Gd-153	13	0.42	1.89
			Gd-153	14	0.41	1.87
			Gd-153	15	0.38	1.69
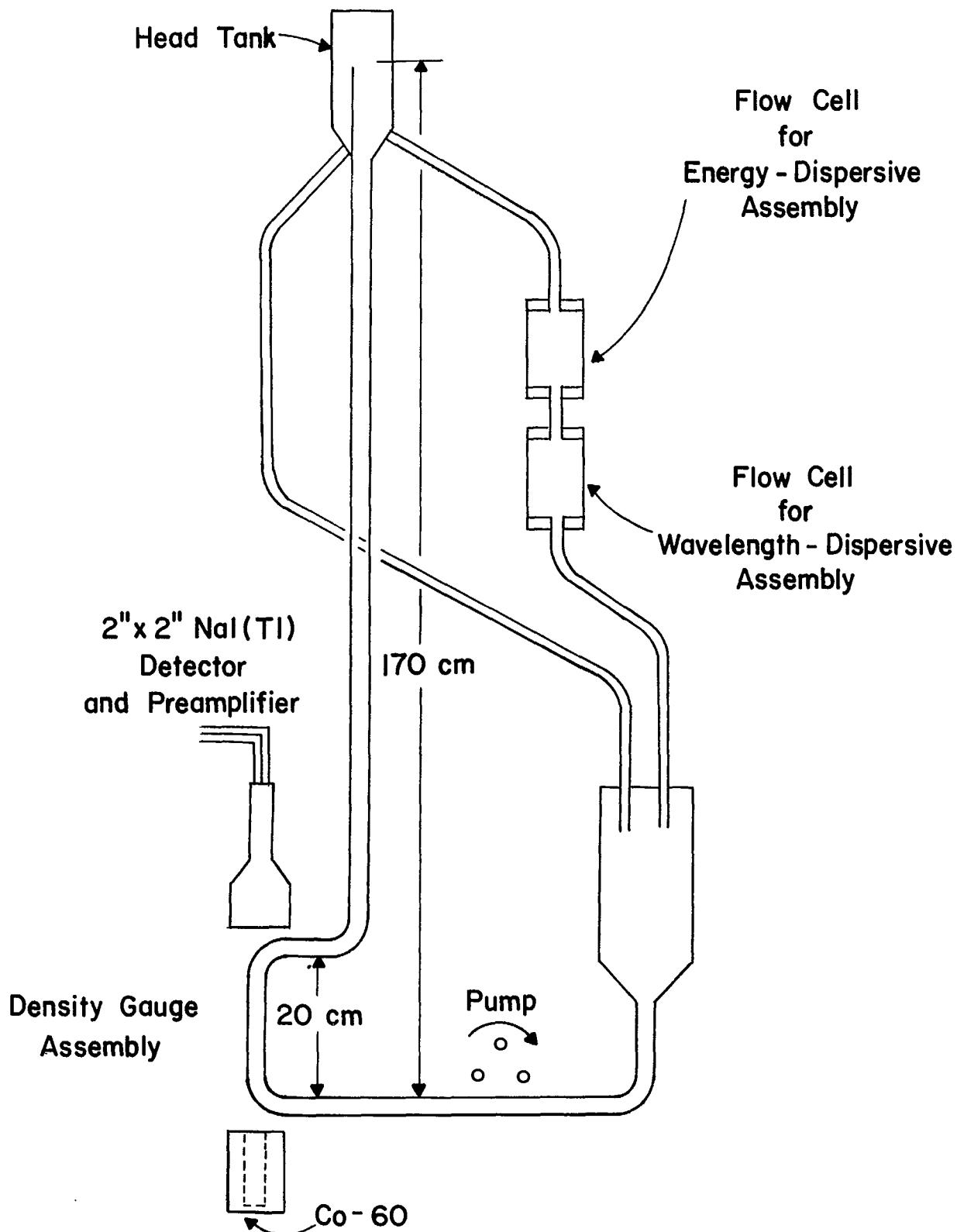
Figure 1. Schematic Diagram of Experimental Test Rig.

Slurry In

Annular
Isotope

Detector
Window

Slurry
Cell

Si(Li) Detector
with Cryogenic Flask

Collimator
Assembly

Slurry Out

ORTEC
H.V.P.S.

ORTEC
716
AMPLIFIER

TRACOR-
NORTHERN
TN-1700-1
PULSE HEIGHT
ANALYZER
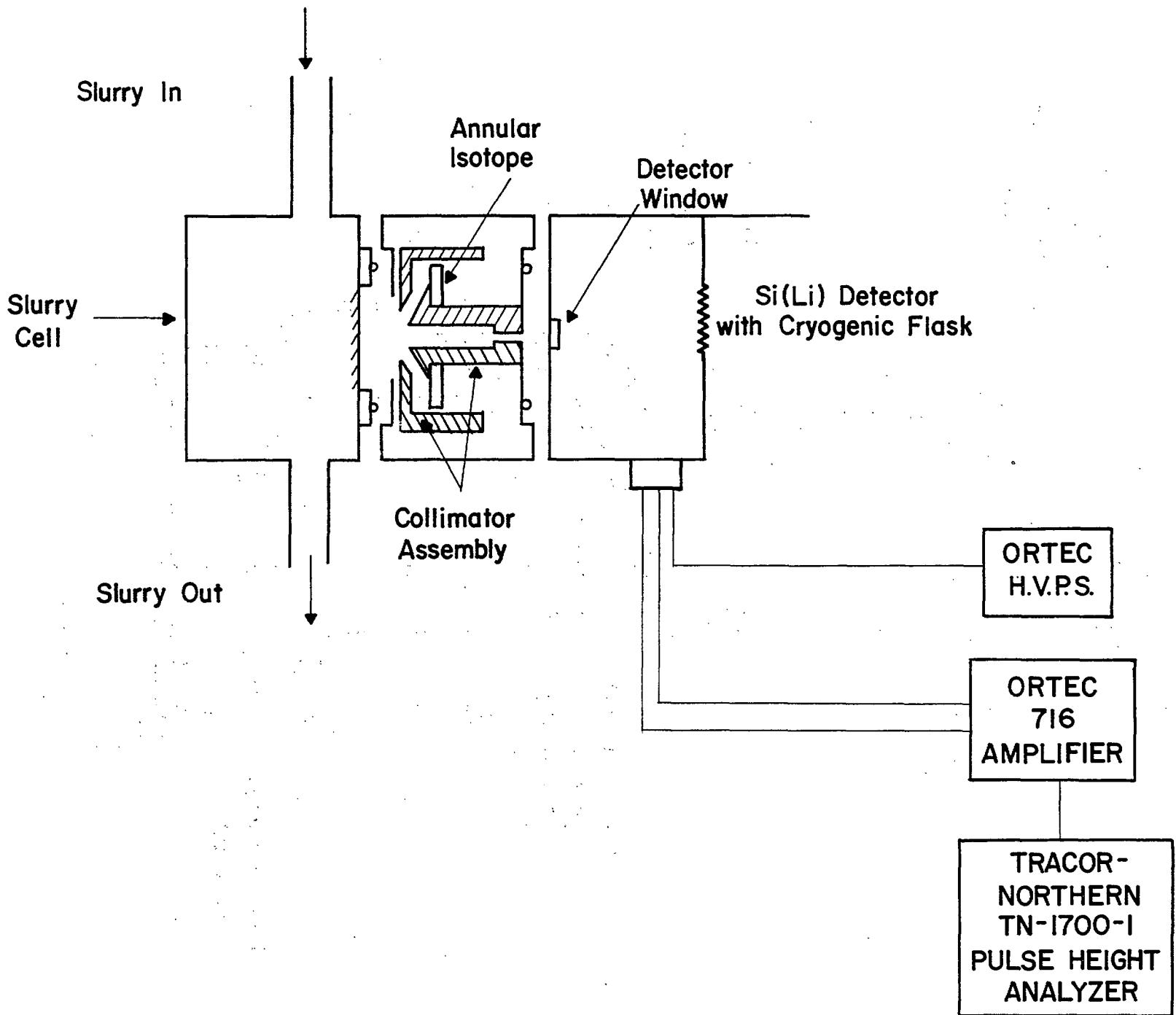
Figure 2. Schematic Diagram of the Single Window Flow
Cell for Energy-Dispersive Assembly.

20
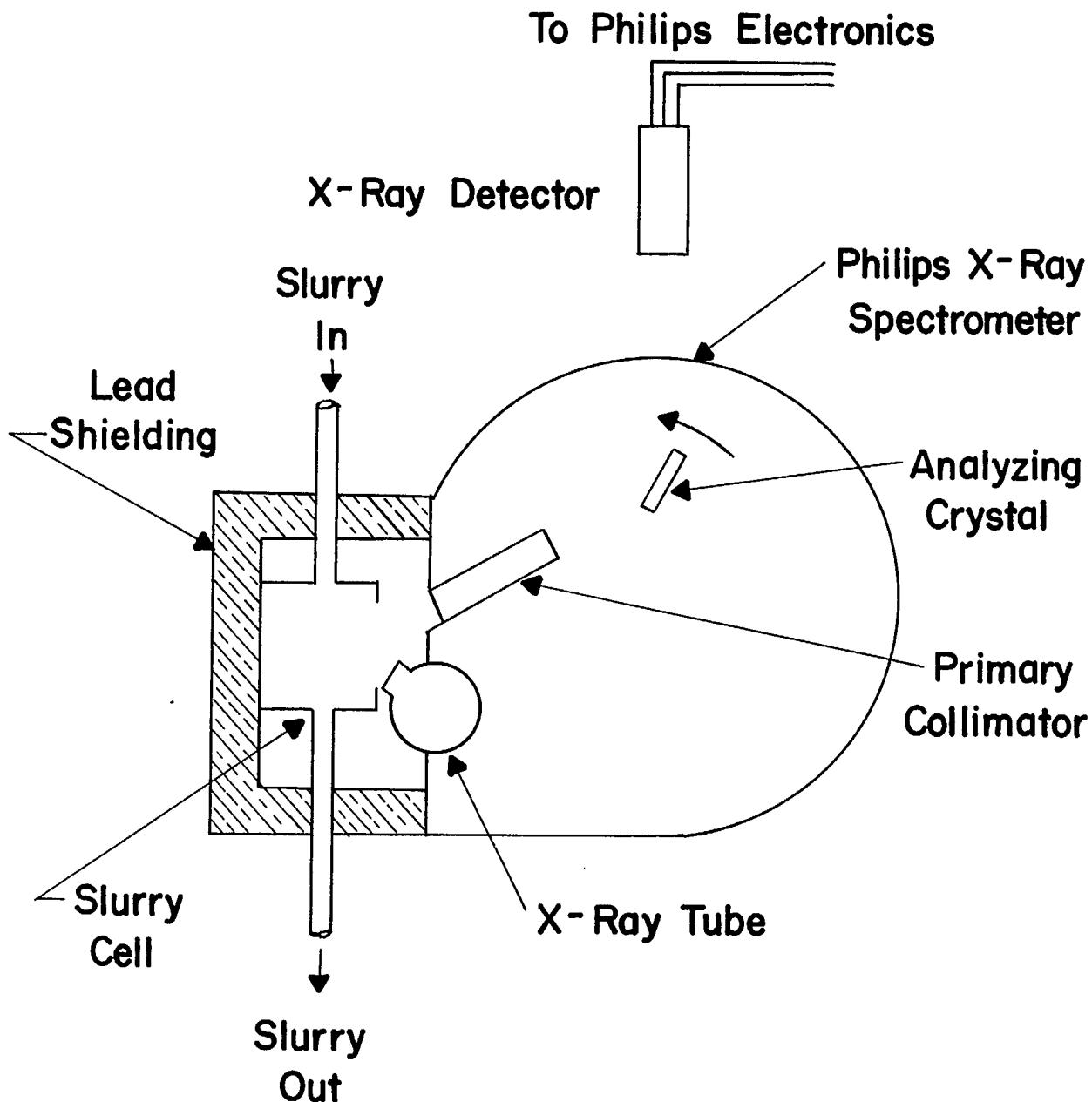
Figure 3. Schematic Diagram of the Philips X-Ray Spectrometer Modified to Accept a Slurry Flow Cell.

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