BuMines OFR 158-77

USBM Contract No. J0265059

PB 274 413

AN EVALUATION OF THE USBM SORTING MACHINE ON NATIVE COPPER ORES OF THE KEWEENAW DISTRICT

for

U. S. Department of the Interior
Bureau of Mines
Building 20, Denver Federal Center
Denver, Colorado 80225

Bureau of Mines Open File Report 158-77

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July 1, 1977

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BIBLIOGRAPHIC DATA SHEET	1. Report No. BuMines OFR 158-77	2.	3. Recipient's Accession No.
4. Title and Subtitle An Evaluation of the USBM Sorting Machine on Native Copper Ores of Keweenaw District			5. Report Date July 1, 1977
			6. Performing Organization Code
7. Author(s) C. W. Schultz and C. W. Karkkainen			8. Performing Organization Rept. No.
9. Performing Organization Name and Address Institute of Mineral Research Michigan Technological University Houghton, MI 49931			10. Project/Task/Work Unit No.
			11. Contract/~~Grant~~ No. J0265059
12. Sponsoring Agency Name and Address Office of Assistant Director--Metallurgy Bureau of Mines U.S. Department of the Interior Washington, DC 20241			13. Type of Report & Period Covered Contract research
			14. Sponsoring Agency Code

15. Supplementary Notes
Approved for release by Director, Bureau of Mines, November 15, 1977.

16. Abstracts This report is a comprehensive evaluation of a Bureau of Mines developed induction balance sorting machine for separating rock fragments that contain metal from those that do not. The machine was evaluated using run-of-mine ore containing native copper from the Kingston and Centennial mines and waste rock that contains copper metal from the Champion mine. The tests show that the sorter is capable of sorting efficiencies of 91.5% with a 97+% availability. Calculations suggest that, if the capacity of the machine can be increased, the cost of mining native copper ores could be reduced.

17. Key Words and Document Analysis. 17a. Descriptors

Metallurgy
Copper
Ore beneficiation
Separation
Electromagnetic induction

17b. Identifiers/Open-Ended Terms

17c. COSATI Field/Group 01/07

18. Distribution Statement	19. Security Class (This Report) UNCLASSIFIED	21. [illegible]es
Release unlimited by NTIS.	20. Security Class (This Page) UNCLASSIFIED	22. Price MF PC A04 / A01

FORM NTIS-35(10-70) US COMM-DC 40329-P71

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INTRODUCTION

The native copper deposits of the Keweenaw Peninsula of Michigan constitute an important national resource. These ores were mined continuously from 1844 to 1968 producing over 10 billion pounds of primary copper. When mining ceased in 1968, due to labor difficulties and unfavorable economic conditions, the available reserves were estimated to be in excess of one billion pounds in ores ranging from 20 to 30 pounds per ton.[1] The total reserves of the district including the marginal ores are many times that amount. Estimates range from 10 to 100 billion pounds of recoverable copper. These resources cannot, under present or foreseeable conditions, be economically recovered. Economic exploitation of the native coppers will require the development of new technology.

It has long been recognized that sorting is a technology which has the potential of measurably reducing the cost of recovering native copper. Hand sorting was practiced at the Champion mine until the depression of the 1930's. As early as 1928 investigators at Michigan Technological University (at that time Michigan College of Mining and Technology) were attempting to develop mechanized sorting methods for native copper and other ores.[2] The basis for the interest in sorting native copper is two fold; first the copper is distinctly segregated in the ore veins; and second, copper possesses properties which make it readily detectable.

In 1965 International Sorting Systems Corporation (ISSC) developed a sorting machine specifically for native copper ores. In 1967 tests on the ISSC machine were conducted at the Institute of Mineral Research.[3] A comprehensive test program on the ISSC system was conducted at the plant of the Mineral Recovery Corporation (an ISSC subsidiary) during late 1971 and early 1972. That program, supported jointly by the Institute of Mineral Research, the U. S. Bureau of

Mines (Twin Cities Mining Research Center), and the Upper Great Lakes Regional Commission, demonstrated that the ores of the district are generally amenable to sorting and that an economic advantage can be realized by sorting.[4]

Independent of these efforts the U. S. Bureau of Mines Rolla Metallurgy Research Center developed an electronic sorting machine for native copper. This machine, which employs a different electronic scheme for copper detection than does the ISSC machine, has been extensively tested in the Bureau laboratories.[5]

The Institute of Mineral Research has conducted an intensive pilot plant scale study of the Bureau machine. The objective of that study has been to evaluate the sorting machine in terms of its metallurgical performance, reliability and economic impact on native copper production. This report describes the test program, the results, the analytical methods employed and the conclusions and recommendations drawn therefrom.

SORTING TEST PROGRAM

Samples

Three native copper bearing materials were selected for use in this test program. They were run of mine ore from the Kingston and Centennial mines and waste rock from the Champion mine. The Kingston and Centennial mines are in conglomeritic ore bodies while the Champion mine is in an amygdaloidal vein. These materials were selected because in total they represent a cross section of the resources available in the district and because prior experience has shown that each material is amenable to sorting.

Kingston ore. The Kingston conglomerate is relatively fine grained with felsite pebbles being generally smaller than one half inch. The copper occurs in lenses as the cementing material between the felsite pebbles. The lenses average between 2 and 3 inches in thickness and may be as much as 2 ft. in length and width. The copper is highly interconnected within the lenses. Only minor amounts of copper occur outside the copper rich lenses and virtually none is dispersed within the felsite pebbles. The Kingston ore is known to be highly sortable. Previous sorting tests have achieved copper recoveries as high as 96% in the coarse size fractions. The sortability and grade correlate strongly with the size of the "as mined" ore, the coarser sizes being higher in grade and more sortable.(6)

Centennial ore. The Centennial conglomerate differs from the Kingston in that the felsite pebbles are generally coarser, ranging up to 3 inches in diameter. The copper again occurs in lenses. The lenses, however, are less distinct and the copper appears to be less continuous. There are frequent occurrences of copper outside the lenses and some fine copper dispersed within the felsite pebbles. Centennial ore is generally higher in grade than the Kingston but slightly less sortable.[6]

Champion poor rock. The copper in the Champion amygdaloid occurs as fillings in the vesicles in a lava flow. The size of the vesicles and hence the copper size is highly variable. The copper exists as discreet inclusions with few or no interconnections. Epidote and calcite are common, which is typical of amygdaloidal ores. Previous sorting tests on Champion waste rock have indicated grades ranging from 3 to 5 pounds of copper per ton, approximately 70% of which is recoverable.

Preparation of Ore for Sorting

Each of the three samples was, upon receipt, screened successively on 4", 2" and 1" screens. The plus 4" rock was crushed and rescreened. The -4"/+2" and the -2"/+1" size fractions were weighed and stored in barrels. Amounts in excess of sorting test requirements were taken to the IMR bulk ore storage area. The -1" fractions were weighed, sampled for subsequent chemical analysis and stored. The weights and size distribution of the three samples after crushing to pass 4" are presented in Table 1. Note that in the Centennial sample a +4" fraction is indicated. This represents a single piece of massive copper which could not be crushed.

The USBM Sorting Machine

The electronic principles employed in the sorting machine developed by the USBM Rolla Metallurgy Research Center have been described in some detail in published literature.[5] In essence, the sorter uses the induction balance method in which there are two coils, one for excitation, the other for pick up. A conductor in the field between the coils causes an increase in the voltage in

Table 1

Weight, Size Distribution and Copper Content of Crude Ore Samples

Centennial

Size	Wt (lbs)	% Wt	% Cu	Cu Dist
+4"	215	0.30	29.40	5.91
-4"/+2"	24,082	33.32	1.46	32.60
-2"/+1"	16,729	23.14	1.09	16.89
-1"	31,249	43.24	1.54	44.60
	74,275	100.00	1.49	100.00

Kingston

Size	Wt (lbs)	% Wt	% Cu	Cu Dist
-4"/+2"	49,818	42.71	1.04	40.00
-2"/+1"	26,961	23.12	1.24	25.80
-1"	39,851	34.17	1.11	34.20
	116,630	100.00	1.11	100.00

Champion

Size	Wt (lbs)	% Wt	% Cu	Cu Dist
-4"/+2"	16,247	22.19	0.20	29.13
-2"/+1"	16,861	23.03	0.16	24.15
-1"	40,099	54.78	0.13	46.72
	73,207	100.00	0.15	100.00

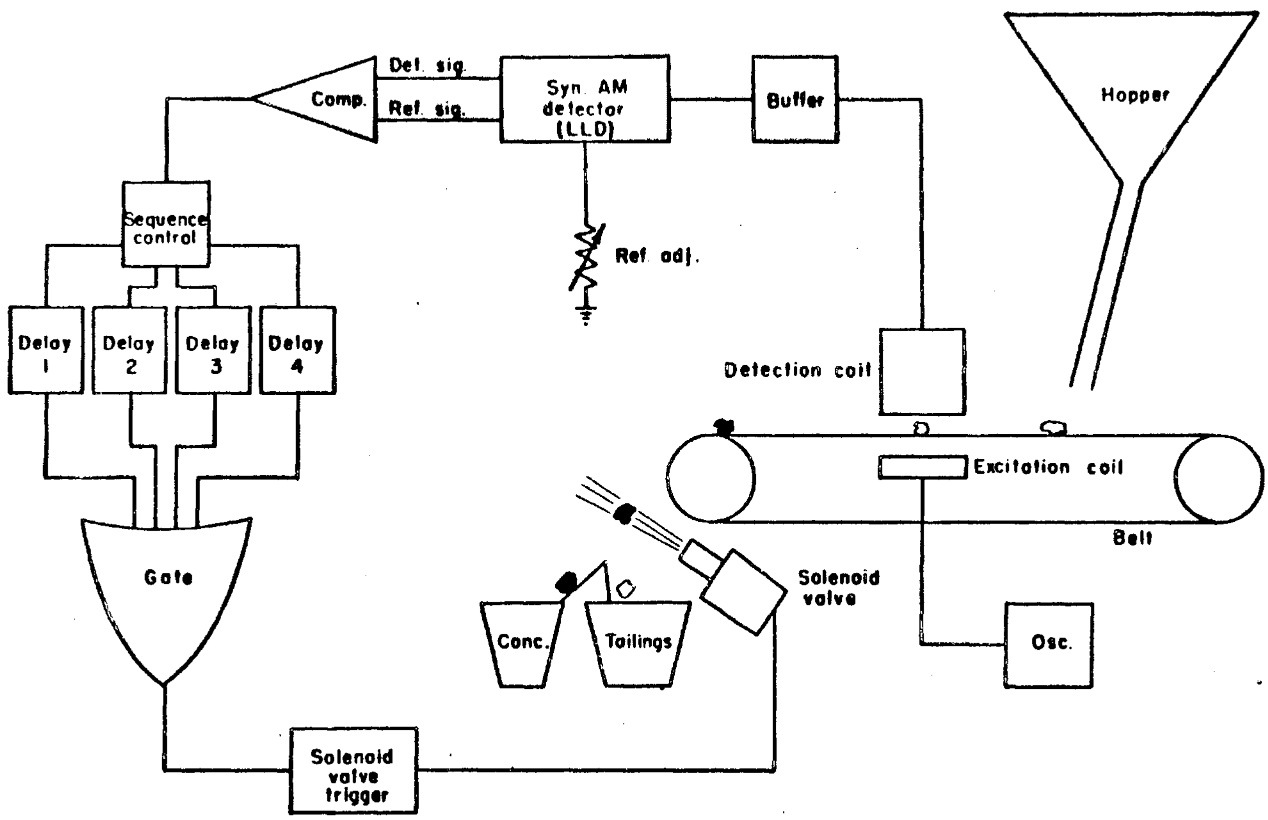

Figure 1. Functional Block Diagram of Detector and Ore Sorter

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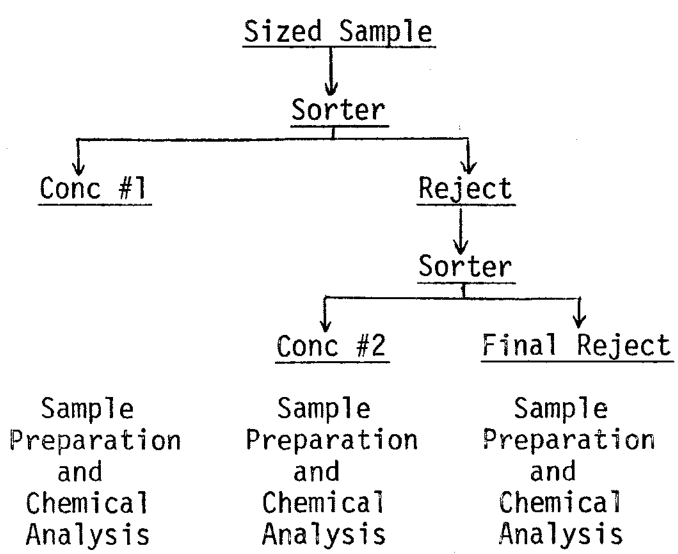
failure or instability of the sorter occurred. All starting and stopping times were recorded for the purpose of establishing the operating capacity and the reliability of the sorter. The daily log of operations is presented in Appendix A. After an entire size fraction of a sample had been sorted, the concentrate was weighed and set aside to be prepared for chemical analysis. The reject was again sorted under conditions identical to those in the first pass. The products of the second sort were both weighed and set aside to be prepared for chemical analysis. A flowsheet illustrating the double sorting operation is presented in Figure 2. The purpose in double sorting was to generate data by which the sorter operation could be evaluated independently of the nature of the ore. The methods used in making this evaluation will be described in a later section.

Figure 2

Sorting Flowsheet



Preparation of samples for chemical analysis. The segregation of values in native copper ores which makes them highly sortable also precludes accurate sampling, particularly at coarse rock sizes. Therefore, in order to obtain accurate data on the performance of a sorting operation, it was necessary to process sorter products in their entirety through the sample preparation procedure illustrated in Figure 3.

The product was first weighed and stage crushed to 1/2-inch. The residual +1/2-inch material, comprised principally of metallic copper, was then weighed and the copper content determined by specific gravity analysis. The -1/2-inch material was then blended and reduced by riffling to retain a sample of approximately 200 lbs. That sample was stage crushed to 1/4-inch and the weight of +1/4-inch metallic copper determined. This procedure was repeated at 10 mesh and at 100 mesh with a final sample of about 50 gms of -100 mesh material being analyzed for copper by conventional chemical methods. The method is particularly appropriate for sorter products in that not only does it yield accurate results but also provides data on the size distribution of the copper upon which the detection limits of the sorter can be assessed.

Sorting Test Results

The results of the sorting tests, performed in the manner described in the previous section, are summarized in Table 2. In that table all copper and weight distributions are calculated on the basis of sorter feed.

Tables 3, 4 and 5 show the distribution of copper among sorter products by copper size for the Kingston, Centennial and Champion ores respectively.

Figure 3

Sample Preparation
Native Copper Ore Separation Products

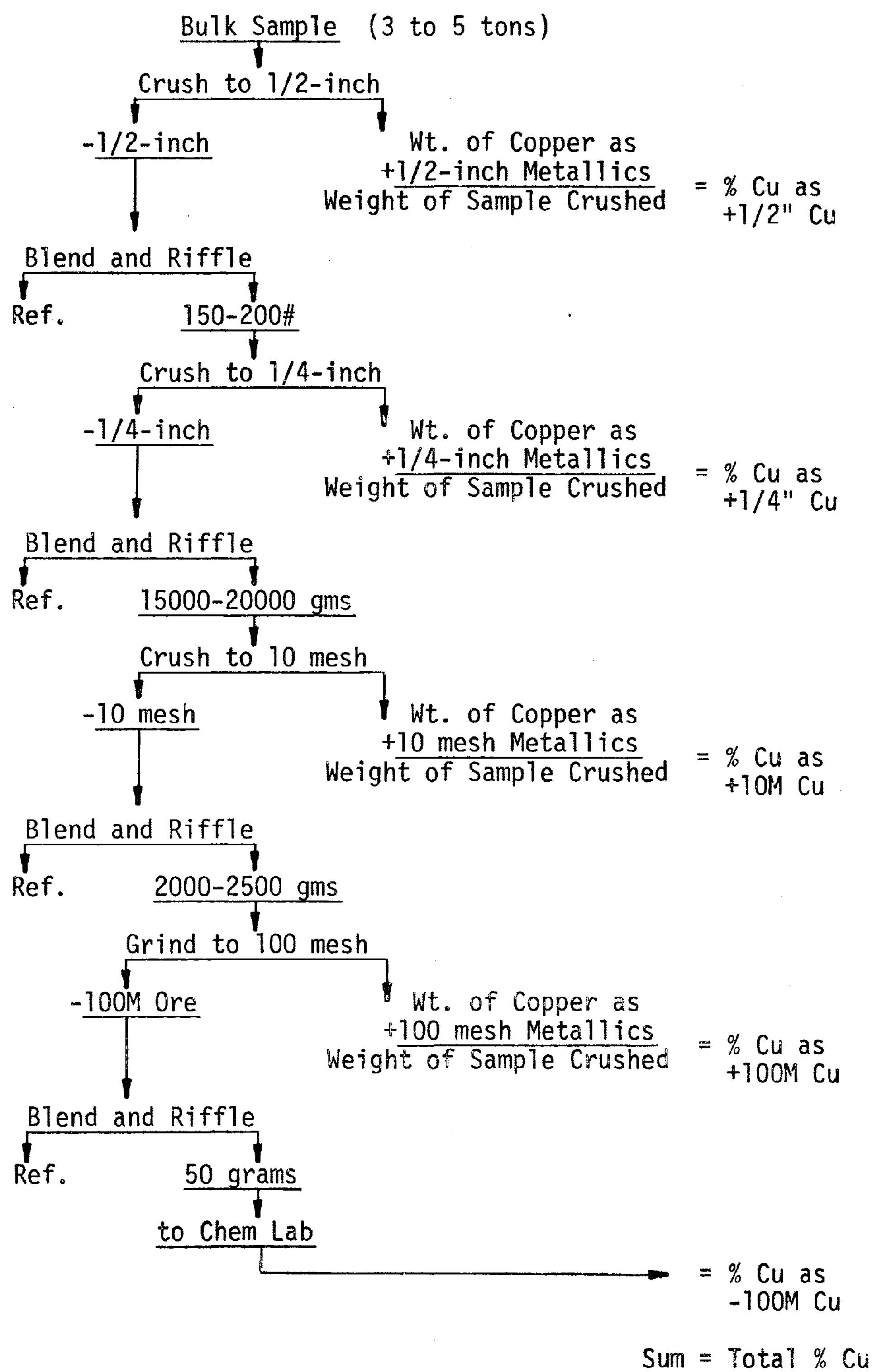


Table 2

Weight and Copper Distribution of Sorter Products

Kingston Conglomerate Rock Size (inches)	Product	Weight Pct.	Copper Pct.	Distribution Cu Pct.
4x2	Conc. 1	25.4	3.11	75.9
	Conc. 2	7.9	1.32	10.0
	Conc. 1 + 2	33.3	2.68	85.9
	Final Reject	66.7	0.22	14.1
	Head	100.0	1.04	100.0
2x1	Conc. 1	36.5	2.94	86.8
	Conc. 2	6.4	0.75	3.8
	Conc. 1 + 2	42.9	2.61	90.6
	Final Reject	57.1	0.20	9.4
	Head	100.0	1.24	100.0
Centennial Conglomerate				
4x2	Conc. 1	29.5	3.99	80.4
	Conc. 2	7.1	1.00	4.9
	Conc. 1 + 2	36.6	3.41	85.3
	Final Reject	63.4	0.34	14.7
	Head	100.0	1.46	100.0
2x1	Conc. 1	27.6	2.94	73.9
	Conc. 2	9.8	0.75	6.7
	Conc. 1 + 2	37.4	2.36	80.6
	Final Reject	62.6	0.34	19.4
	Head	100.0	1.09	100.0
Champion Amygdaloid				
4x2	Conc. 1	12.5	1.18	73.6
	Conc. 2	4.1	0.27	5.4
	Conc. 1 + 2	16.6	0.96	79.0
	Final Reject	83.4	0.05	21.0
	Head	100.0	0.20	100.0
2x1	Conc. 1	12.5	0.86	66.6
	Conc. 2	1.9	0.62	7.4
	Conc. 1 + 2	14.4	0.83	74.0
	Final Reject	85.6	0.05	26.0
	Head	100.0	0.16	100.0

Table 3

Kingston Conglomerate

Copper Distribution by Metallics Size

Rock Size	Product	Cu %	+½ inch	+¼ inch	+10 Mesh	+100 Mesh	-100 Mesh	Total
4X2 inch	Conc. 1	3.11	1.92	1.54	21.04	25.35	26.01	75.86
	Conc. 2	1.32	0.23	0.07	1.12	2.08	6.50	10.00
	Conc. 1 + 2	2.68	2.15	1.61	22.16	27.43	82.51	85.86
	Final Reject	0.22	0.00	0.00	0.15	1.19	12.80	14.14
	Head	1.04	2.15	1.61	22.31	28.62	45.31	100.00
	% Recovery (1st pass)		89.23	95.84	94.32	88.57	57.40	75.86
	% Recovery (total)		100.00	100.00	99.35	95.84	71.74	85.86
2X1 inch	Conc. 1	2.94	13.55	3.65	14.78	14.07	40.71	86.76
	Conc. 2	0.75	0.56	0.19	0.24	0.39	2.47	3.85
	Conc. 1 + 2	2.61	14.11	3.84	15.02	14.46	43.18	90.61
	Final Reject	0.20	0.00	0.00	0.03	0.60	8.76	9.39
	Head	1.24	14.11	3.84	15.05	15.06	51.94	100.00
	% Recovery (1st pass)		96.04	95.02	98.18	93.46	78.38	86.76
	% Recovery (total)		100.00	100.00	99.79	96.04	83.14	90.61
Minus 1-inch Unsorted Fraction			1.66	1.64	12.23	24.47	60.00	100.00

Table 4

Champion Amygdaloid

Copper Distribution by Metallics Size

Rock Size	Product	Cu %	+½ inch	+¼ inch	+10 Mesh	+100 Mesh	-100 Mesh	Total
4X2 inch	Conc. 1	1.18	18.49	5.13	10.92	11.93	27.08	73.55
	Conc. 2	0.27	2.34	0.04	0.48	0.56	2.01	5.43
	Conc. 1 + 2	0.96	20.83	5.17	11.40	12.49	29.09	78.98
	Final Reject	0.05	0.00	0.00	0.77	3.13	17.11	21.02
	Head	0.20	20.83	5.17	12.17	15.62	46.20	100.00
	% Recovery (1st pass)		88.76	99.13	89.67	76.36	58.62	73.55
	% Recovery (total)		100.00	100.00	93.65	79.93	62.96	78.98
2X1 inch	Conc. 1	0.86	6.77	6.52	14.48	11.20	27.63	66.60
	Conc. 2	0.62	4.10	0.21	0.50	0.60	2.04	7.45
	Conc. 1 + 2	0.83	10.87	6.73	14.98	11.80	29.67	74.05
	Final Reject	0.05	0.00	0.00	0.17	4.66	21.12	25.95
	Head	0.16	10.87	6.73	15.15	16.46	50.79	100.00
	% Recovery (1st pass)		62.27	96.83	95.62	68.04	54.41	66.60
	% Recovery (total)		100.00	100.00	98.91	71.70	58.41	74.05
Minus 1-inch Unsorted Fraction				6.48	13.53	17.18	62.81	100.00

Table 5

Centennial Conglomerate

Copper Distribution by Metallics Size

Rock Size	Product	Cu %	+½ inch	+¼ inch	+10 Mesh	+100 Mesh	-100 Mesh	Total
4X2 inch	Conc. 1	3.99	24.48	4.86	18.10	10.92	22.09	80.45
	Conc. 2	1.00	0.04	0.13	0.77	0.75	3.18	4.88
	Conc. 1 + 2	3.41	24.52	4.99	18.87	11.67	25.28	85.33
	Final Reject	0.34	0.00	0.00	0.21	0.60	13.86	14.67
	Head	1.46	24.52	4.99	19.08	12.27	39.14	100.00
	% Recovery (1st pass)		99.85	97.43	94.88	88.97	56.44	80.45
	% Recovery (total)		100.00	100.00	98.92	95.08	64.60	85.33
2X1 inch	Conc. 1	2.94	11.54	3.11	12.59	11.98	34.66	73.88
	Conc. 2	0.75	0.97	0.32	0.42	0.68	4.29	6.68
	Conc. 1 + 2	2.36	12.51	3.43	13.01	12.66	38.95	80.56
	Final Reject	0.34	0.00	0.00	0.15	1.05	18.24	19.44
	Head	1.09	12.51	3.43	13.16	13.71	57.19	100.00
	% Recovery (1st pass)		92.20	90.57	95.65	87.43	60.61	73.88
	% Recovery (total)		100.00	100.00	98.94	92.36	68.10	80.56
Minus 1-inch Unsorted Fraction			12.79	11.22	18.63	18.09	39.27	100.00

SORTER PERFORMANCE EVALUATION

A fundamental characteristic of sorting which distinguishes it from conventional concentration processes is the requirement that each rock fragment be examined individually. It is further characteristic that each fragment to be selected must be individually acted upon. Thus a modern sorting system performs not one but three functions, singulation, detection and ejection.

While these functions are performed independently, each element is dependent upon the previous function having been performed accurately and the success of the total system is dependent upon all three functions being performed in sequence.

In the development of this sorting machine, investigators at the USBM Rolla Metallurgy Research Center concentrated their efforts on the detector circuitry and the arrangement of the coils. The selection of the ejection system was largely an arbitrary choice which was compatible with the detector and capable of handling a wide range of rock sizes. In the present test program the singulation was achieved with IMR equipment.

The present evaluation of the Rolla machine, therefore, is focused primarily on those attributes which reflect the quality and efficiency of the detector.

Sorting Efficiency

The recovery of values in a sorting operation is a function of two parameters, the sortability of the ore and the efficiency of the sorter. If sortability is defined as the fraction of values in a detectable configuration, and sorting efficiency as the probability of capturing any given rock fragment containing detectable values, then both parameters can be estimated from operating data by the following method:

The recovery in a single pass through the sorter is:

$$\text{Recovery } (R_1) = S \cdot E$$

where

S = sortability

E = sorting efficiency

If the reject from this separation is again sorted the recovery in the second pass is:

$$R_2 = (S - SE)E$$

The ratio of recoveries in the second and first pass is:

$$R_2/R_1 = \frac{(SE) - E(SE)}{SE}$$

$$R_S/R_1 = 1\text{-}E$$

Inherent in this calculation are the assumptions that: 1) the sorter behaves in a probabalistic manner and 2) sortability and sorting efficiency are independent. The first assumption is thought to be valid. The assumption that sortability and sorting efficiency are independent may not be valid in individual cases. Intuitively one would expect that the probability of detecting and capturing a rich fragment would be greater than for a marginal piece.

Despite this possible weakness, the analytical method is useful in making comparative estimates of both sortability and sorting efficiency. These parameters were calculated from the results of the test program as presented in Table 2. The results of that calculation are presented in Table 6.

Table 6

Evaluation of Sortability and Sorting Efficiency

Ore	Rock Size (inches)	Recovery (1st pass)	Recovery (2nd pass)	Sortability (S)	Efficiency (E)
Kingston	4X2	75.9	10.0	87.4	86.8
	2X1	86.8	3.8	90.8	95.6
Centennial	4X2	80.4	4.9	85.6	93.9
	2X1	73.9	6.7	81.3	90.9
Champion	4X2	73.6	5.4	79.4	92.7
	2X1	66.6	7.4	74.9	88.9
				Avg.	91.5

Table 6 shows calculated sorting efficiencies ranging from 86.8% to 95.6% with an average value of 91.5%. These results compare very favorably with the efficiency of a commercially available sorter as demonstrated in Table 7.

Table 7

The Efficiency of the USBM Sorter as Compared with a Commercially Available Sorter

Ore	Rock Size (inches)	Calculated Efficiency	
		USBM	Commercial
Kingston	6X4	--	84.9
	4X2	86.7	--
	2X1	95.6	72.4
	1X½	--	79.1
Centennial	4X2	93.9	--
	2X1	90.9	--
Winona	6X4	--	89.4
	4X2	--	69.3
	2X1	--	64.5
	1X½	--	69.4
Champion	6X4	--	92.8
	4X2	92.7	66.9
	2X1	88.9	68.6
	1X½	--	82.5
	Avg.	91.5	76.3

These data indicate that, in all cases where common data exist, the USBM sorter is clearly superior in terms of sorting efficiency. The average efficiency of the Bureau sorter exceeds that of the commercial machine by 15%.

During the course of the sorting tests it was observed that rock fragments visibly rich in copper were detected before they reached the coil. As a result the solenoid activated gate was triggered early and such pieces were frequently missed. While Tables 3, 4 and 5 show that all of the +½" and +¼" copper was recovered in all cases, the recovery was frequently low in the 1st pass. This indicates that further improvements in the already high efficiencies may be possible.

Sensitivity

It would be difficult, if not impossible, to define exactly what is meant by sensitivity in the context of electronic sorting. In general it may be said that an increase in detector sensitivity is related to its ability to detect values in diminishing size and/or concentration. High sensitivity is a desired attribute of a sorter; however, absolute sensitivity or the ability to detect all values present is to be avoided since in the extreme it implies recovery of the entire ore and hence no separation.

While sensitivity cannot be measured in any absolute sense, it is possible to derive a relative measure from the analysis used in the previous section. In that analysis sortability was defined as the fraction of the total values in a detectable configuration. Thus sortability, as defined, is related to the sensitivity of the sorting machine as well as the characteristics of the ore.

The sortability of Kingston and Champion ores as calculated from test data on the USBM sorter and a commercial sorter are shown in Table 8.

Table 8

Comparison of Sortability Observed with the USBM Sorting Machine and a Commercial Sorting Machine

Ore	Rock Size (inches)	Sortability (%) USBM	Sortability (%) Commercial
Kingston	6X4	--	88.7
	4X2	87.4	--
	2X1	90.8	82.5
	1X½	--	76.0
Champion	6X4	--	84.1
	4X2	79.4	76.0
	2X1	74.9	63.8
	1X½	--	57.9

Again, in all cases where common data are available, the USBM machine is superior in terms of sensitivity as evidenced by the higher percentage of ultimately recoverable copper, i.e., higher sortability. In this case average values have no meaning since the individual values are characteristic of the ore as well as the machine.

There is evidence that the USBM sorter approaches the maximum desirable sensitivity. Note, for example, in Table 2 that the final rejects from the Kingston and Centennial ores approach a grade which is common for mill tailings in this district. The rejects from the Champion waste rock reach an extremely low value of 1 lb Cu/ton. In Tables 3, 4 and 5 it can be seen that the major fraction of the losses are -100 mesh copper. These data imply that for the ores studied, any further increase in sensitivity, as would be required to detect the -100 mesh copper, would increase the recovery by a minimal amount while decreasing the grade of the concentrate.

Reliability

The reliability of any system is a matter of interest in that both the

availability of the system and the amount of repair time and hence operating cost are a function of reliability. In the performance of the sorting tests all starting and stopping times were entered into the operating log along with comments stating the reason for the interruption. In sorting all of the 4X2 inch samples only 2 failures were noted in a total operating period of 45.76 hours. The reliability analysis is restricted to those functions of the sorter which represent a Bureau development, hence only those failures related to the detector circuitry are included. A failure of the ejector mechanism, for example, due to a defective part was observed but is not included in the analysis. From the observations, then, the mean time to failure (θ) is 22.88 hours. In the terminology of reliability engineering the reliability of the system over a time period t is:

$$R = e^{-t/\theta}$$

This is the probability that no failures will occur in the time interval from 0 to t. Thus for an operating shift of eight hours the probability of no failures is:

$$R = e^{-8/22.88} = 0.705$$

When the sorter was readjusted to accomodate 2X1 inch rock 10 failures were observed in a total operating period of 71.11 hours, or $\theta = 7.11$. The reliability for an operating shift is then:

$$R = e^{-8/7.11} = 0.325$$

The observed failures (instabilities in the detector) were readily corrected by adjusting the coil position or by adjusting the signals to reestablish the null signal in the pick up coil. In the twelve failures observed the repair times ranged from 3 to 40 minutes with an average of ten minutes. The expected availability of the sorter operating on 2X1 inch rock then is:

$$A = \frac{\theta}{\theta + \text{Repair Time}} = 97+\%$$

The total period of observation of the sorter was too short to permit a statistically valid estimate (90% confidence) of the sorter reliability. However, with that qualification, the USBM sorting must be rated as acceptable in terms of its reliability.

Capacity

During the performance of the sorting test program, the weight of each addition of ore to the feed and all starting and stopping times were entered into the daily operating log. These data are presented in Appendix A. From the operating log the total weight and operating times for each ore and each size was assembled and the operating capacity calculated. These data are summarized in Table 9.

Table 9 shows the sorter to have an average capacity of 1.51 tons/hr on 4X2 inch feed and 0.238 tons/hr on 2X1 inch feed. These levels of capacity are highly unsatisfactory in relation to the observed capacity of other sorters. For example, a commercial belt sorter operating on 4X2 inch native copper ore had observed capacities in the range from 15 to 25 tons/hr and a rotary sorter (multi-channel) operating on 2X1 inch rock had an observed capacity of 25 tons/hr. A scanning type optical sorter is claimed by the manufacturer to have a capacity of 60 metric tons/hr on nominal 12 mm (1/2") feed and 120 metric tons/hr on 75 mm (3") feed.

The capacity limiting feature of the sorter as tested here is the solenoid activated gate used for ejecting concentrate. In RI 7904 it was shown that the cycle time for this device is on the order of 250-300 milli seconds. Private

Table 9

Observed Feed Rates

Ore	Rock Size (inches)	Pass	Tons	Hours	TPH
Kingston	4X2	First	5.56	3.70	1.51
Kingston	4X2	Second	11.22	8.63	1.30
Champion	4X2	First	8.29	5.50	1.51
Champion	4X2	Second	7.10	3.63	1.95
Centennial	4X2	First	12.04	8.19	1.47
Centennial	4X2	Second	8.45	6.32	1.34
				Avg.	1.51
Centennial	2X1	First	3.06	12.35	0.25
Centennial	2X1	Second	1.81	9.22	0.20
Kingston	2X1	First	3.14	12.63	0.25
Kingston	2X1	Second	2.01	7.42	0.27
Champion	2X1	First	3.31	13.85	0.24
Champion	2X1	Second	2.72	12.20	0.22
				Avg.	0.24

communications with the USBM personnel have indicated that an improvement in capacity by a factor of 15 is achievable within the present state of the art. Further improvements in the capacity of the 2X1 inch sorter could be achieved by the design of a multi channel device.

ECONOMIC EVALUATION

In addition to observing and evaluating the performance characteristics of the USBM sorter, it was the further objective of this investigation to evaluate the sorter from an economic view. The economic analysis consists of a determination of the capital and operating costs of a sorting plant and a determination of the impact of sorting on the break-even price of copper as compared with conventional technology.

In performing the economic analysis, a basis for comparison was chosen which reflects the local situation and could be implemented in this district. The basis is a constant milling rate of 1000 tons per day. The selection of this basis shows the potential, with sorting, of increasing output and revenue with a minimal increase in capital outlay. The two cases being compared are described as follows:

Case I - Conventional Technology

Ore - Kingston
Grade - 1.11% Cu
Mining Rate - 1000 TPD
Mining Cost (Direct) - $9.50/ton
Mining Capital Costs

Preproduction Development	$12,245,000
Underground Plant	2,300,000
Surface Plant	1,800,000
Working Capital	850,000
Total	$17,195,000

Milling Costs - $3.80/ton mined
Milling Capital Cost - $5,000,000
Working Capital - $325,000
Net Copper Recovery - 90%

Case II - Sorting

Ore - Kingston
Grade - 1.11% Cu
Mining Rate - 1715 TPD
Mining Cost - $9.50/ton
Mining Capital Costs

Preproduction Development	$13,340,000
Underground Plant	3,450,000
Surface Plant	1,800,000
Working Capital	1,425,600
Total	$20,015,600

Milling Cost (Direct) - $2.216/ton mined
Milling Capital Cost - $5,000,000
Milling Working Capital - $325,000
Sorting Cost (Direct) - $0.794/ton mined
Sorting Plant Capital Cost - $1,466,125
Working Capital - $119,160
Net Copper Recovery - 85.61%

In defining these cases no attempt was made to optimize the size of the operations nor to analyze the effects of various financing alternatives. It is assumed that the reserves are adequate to support either case.

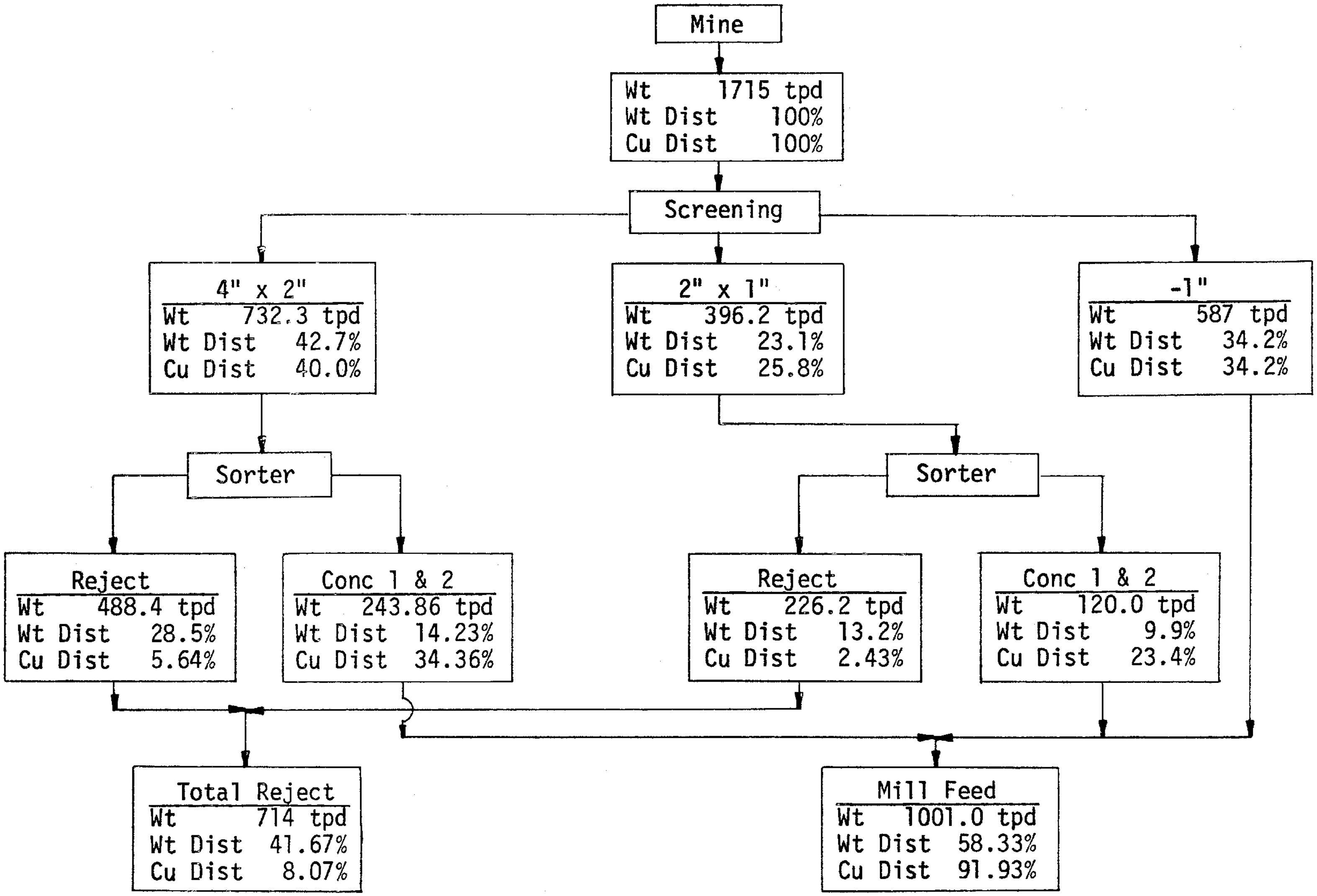
The mining rate in Case I was selected arbitrarily. The mining rate in Case II was calculated from the weight distribution of the Kingston ore as received (Table 1) and the weight recovery (Table 2) so as to yield 1000 tons per day of combined sorter concentrate and -1" ore. For purposes of illustration a copper and a material balance for Case II are shown in Figure 4.

The mining and milling costs used in this analysis were obtained from a local company with recent experience in native copper operations. These costs compare closely with estimates made by updating the 1974 estimate by Schultz[7].

Figure 4

METAL & MATERIAL BALANCE

Case II



The cost increases since that date are due primarily to labor, 50%, and power, 500%, cost increases.

The capital cost of the mine was calculated by updating the estimate by Schultz[7] with more recent shaft sinking and drifting costs experienced in a local mine. These costs are very similar in both Case I and Case II. The reason for the similarity is that certain major costs such as shaft sinking (both haulage and service shafts) remain constant in both cases. Likewise the surface plant costs (primarily the hoist) do not change. All other costs such as haulage drifts, stope preparation, underground equipment and working capital have been adjusted to reflect the increased mining rate.

Local experience was again used to establish the capital cost of the mill. A 750 tpd mill was erected in 1975 at a cost of 3.5 million dollars. Inflating the price by 8% and the capacity by a factor of 1/3 yields a current price of 5 million dollars. This is in agreement with the industry average cost of a simple flotation plant.

Cost Analysis - Sorting

Because the capital and operating costs of the sorting plant are of primary concern in this report a detailed estimate was made using the methods and data of Parkinson and Mular[8]. The estimate is based on two assumptions; first that an increase in capacity of the sorter by a factor of 15 could be achieved without major development expense and second that the sorter could be built and sold profitably for $5000.

It was stated earlier that the capacity limiting feature of the sorter is the response and recovery time of the ejector gate. The cycle time in the present configuration is 250-300 milli seconds. An AC solenoid activated air valve is capable of 15-20 millisecond cycle time. The air valve could be used with the present detector circuit by incorporating a photo cell gating circuit to index the position of each rock fragment and limit time during which it was examined by the detection coil. The number of storage registers would also have to be increased to compensate for the increased number of rock fragments between the coil and the air valve. This approach to increasing sorter capacity has been suggested by Bureau personnel familiar with the machine. We conclude that the assumption is realistic.

The purchased cost of the electronic components of the prototype machine is approximately $500. If an additional $500 were allowed for the photo cell gating circuit and storage registers and $1000 for the conveyor frame, belt and motor, the cost of the sorter components is $2000. This allows $3000 for assembly, marketing, delivery and profit.

The purchased equipment cost of a sorting plant capable of double sorting 732 tpd of 4X2 in ore and 396 tpd of 2X1 in ore is itemized in Table 10. From this data a total capital cost was estimated using the Parkinson-Mular method. The data are shown in Table 11. An operating cost estimate is itemized in Table 12.

These estimates show that an increase in capacity of 715 tpd can be effected for a capital investment of $1,466,125. An investment of $3,575,000 would be required to gain that capacity through the use of conventional technology. The operating cost of the sorting plant is only $0.794/ton as compared with $3.80/ton for milling.

The estimated operating cost of the sorting plant is high compared with the claims of a manufacturer of a photometric sorter. They claim, in sales literature, a cost of $0.10 to 0.15/ton. This estimate, however, is based on South African labor and power costs.

Table 10

Purchased Equipment Cost Estimate - Sorting

Item	No.	Unit Cost	Total Cost
Crude Ore Bin (1000 T)	1	$25,000	$25,000
Conveyor (1) 24" x 50'	1	5,000	5,000
Double Deck Screen	1	12,000	12,000
Conveyor (2) 24" x 50'	2	5,000	10,000
Feed Bin (200 T)	2	5,000	10,000
Apron Feeders 18" x 10'	7	6,000	42,000
Single Line Feeders	7	3,000	21,000
Sorters (Primary)	7	5,000	35,000
Conveyor (3) 24" x 30' (4X2 tail)	1	3,000	3,000
Conveyor (4) 24" x 70' (2X1 tail)	1	7,000	7,000
Feed Bin (100 T) (2X1 tail)	1	2,000	2,000
Single Line Feeder (4X2 tail)	1	3,000	3,000
Pan Feeder (2X1 tail)	3	6,000	18,000
Single Line Feeders	3	3,000	9,000
Sorters (Secondary)	4	5,000	20,000
Conveyors - Conc. Trans. 24" x 50'	4	5,000	20,000
Conc. Conveyor 24" x 50' (Main)	1	20,000	20,000
Conc. Storage Bin	1	25,000	25,000
Tailing Trans. Conc. 24" x 50'	2	5,000	10,000
Tailing Conveyor 24" x 100'	1	10,000	10,000
Tailing Bin	1	12,500	12,500
Compressor	1	50,000	50,000
TOTAL			$358,000

Table 11

Capital Cost Estimate - Sorting

1.	Purchased Equipment Cost	$ 358,000
2.	Installed Equip. Cost 1.5 x (1)	537,000
3.	Process Preparing 5% of 2	26,900
4.	Instrumentation 10% of 2	53,700
5.	Building and Site Development 75% of 2	402,750
6.	Auxillaries	-0-
7.	Outside Lines 5% of 2	26,900
8.	Total Physical Plant	1,047,250
9.	Engineering and Construction 25% of 8	261,800
10.	Contingency 10%	104,725
11.	Size Factor	52,350
	TOTAL	$1,466,125

Table 12

Operating Cost Estimate - Sorting

	Annual Cost	Cost $/ton feed	Cost $/lb Cu Rec
Power - 150 kw hr/hr @ 0.05/kw hr	$ 63,000	$ .1049	$0.0055
Direct Labor - 3/shift @ 6.00/hr	151,000	.2515	0.0132
Supervision 15%	22,680	.0378	0.0020
Maintenance - 2x 1/2/shift @ 7.00/hr	58,800	.0979	0.0052
Supervision 15%	8,820	.0147	0.0008
Parts	58,800	.0979	0.0052
Payroll Overhead (25%)	60,375	.1006	0.0053
Sub Total - Direct Costs	423,675	0.7053	0.0372
Indirect (12.5% of Direct)	52,960	.0882	0.0046
Total Operating Cost	$476,635	$0.7935	$0.0418

Investment Analysis

The return on investment in Cases I and II, as defined earlier, were compared using an economic simulation program developed by Wilborn and Bennet. The program is described briefly in Appendix B. The return on investment was calculated in both cases for a series of copper prices ranging from \$0.70/lb to \$1.05/lb. The results are tabulated in Table 13 and presented graphically in Figure 5. The prices shown are for copper concentrates at the mill. The corresponding price of refined copper would be approximately \$0.10/lb higher.

These calculations show that, for the cases as defined, sorting could reduce the break even price by ∿\$0.05/lb. The reduction in the price required to produce an acceptable 15% R.O.I. after taxes is approximately \$0.15/lb. Neither case, however, is feasible under present economic conditions.

Table 13

Return on Investment (ROI)
as a Function of Copper Price

Price/lb	ROI (%) Case I (Conventional Technology)	ROI (%) Case II (Sorting)
$ .70	0.00	0.00
.75	0.00	0.05
.80	0.44	2.78
.85	2.38	5.42
.90	4.44	7.86
.95	6.30	10.21
1.00	8.06	12.35
1.05	9.72	14.41
1.10	11.38	16.24
1.15	12.75	17.92
1.20	13.92	19.48
1.25	15.19	21.14

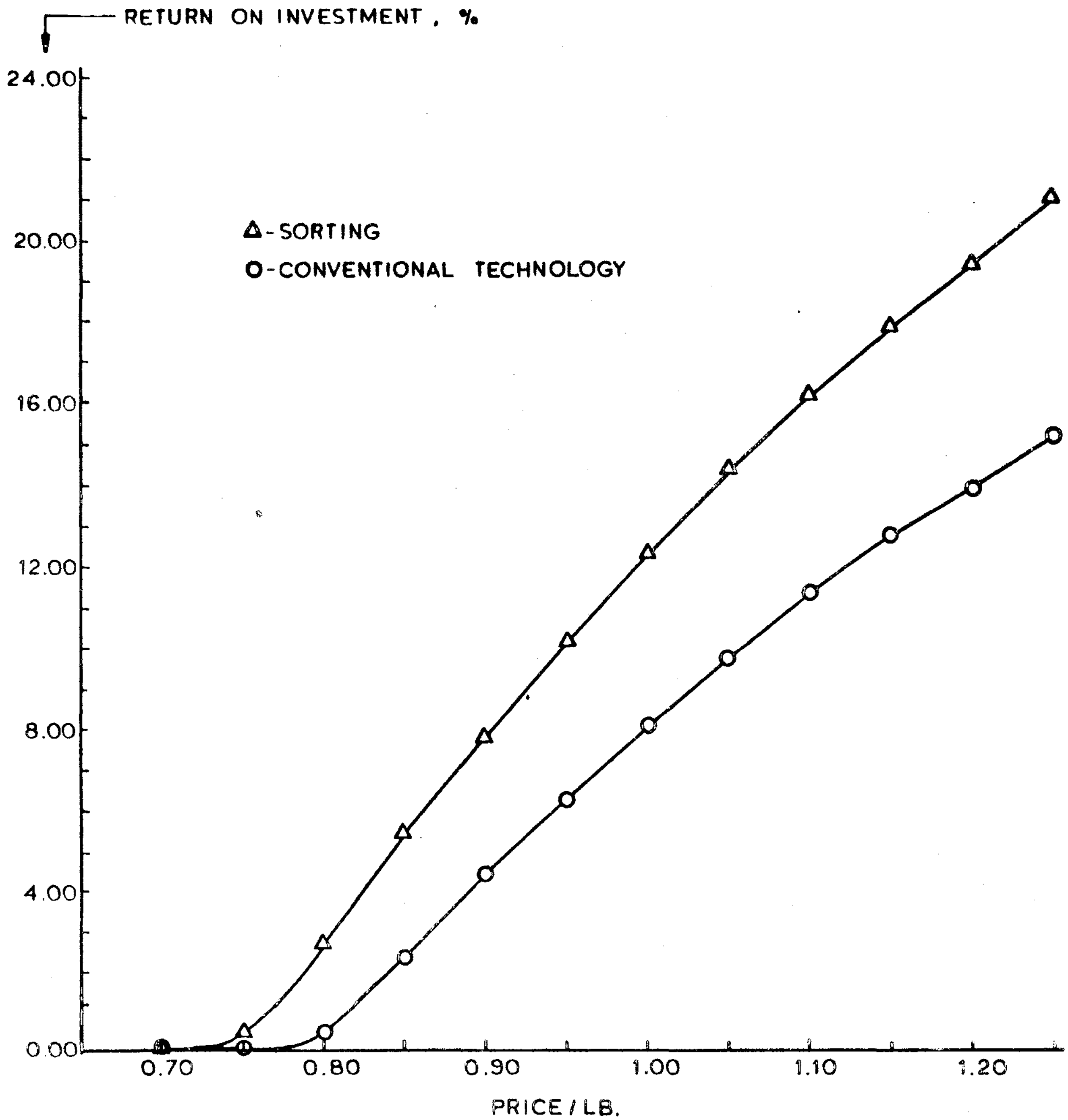


Figure 5. Return on Investment (ROI) as a Function of Copper Price

SUMMARY AND RECOMMENDATIONS

Sorting tests were conducted on three native copper bearing materials; Kingston conglomerate ore, Centennial conglomerate ore, and waste rock from the Champion mine. Two sizes, 4X2 in and 2X1 in, of each sample were sorted with the reject from the first pass being returned for resorting.

Analysis of the sorter products showed recoveries ranging from 74.0 to 90.6% of the contained copper. The analyses also showed that the losses were almost entirely copper which occurred in the rock at sizes finer than 100 mesh.

An evaluation of the sorter performance showed that the sorter is more efficient (91.5%) than other sorters which have been examined. A high sensitivity and reliability were also observed.

The major deficiency in the sorter is the low throughput which can be achieved in its present configuration. It is believed, however, that significant increases can be achieved with state of the art technology.

An economic analysis, based on an assumed capacity increase, shows that sorting could greatly improve the economics of native copper production. Economic feasibility under present conditions, however, could not be achieved.

In future sorter development it is recommended that the total sorting system be approached rather than simply the detection system. Multichannel sorters or those which do not require singulation are recommended. These type sorters have the potential of achieving high capacity on fine sized feed, which has historically been a problem in sorter development. Should further efforts be focused on the existing sorting machine, it is recommended that the fast response AC solenoid air valve with a photo cell indexing circuit be integrated into the sorter to achieve the higher capacities which have been forecast.

Sorting is conservative of both energy and capital which are critical to the production of minerals at competitive costs; it is therefore recommended that the Bureau continue to promote the development and implementation of sorting in the mineral industry.

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Appendix A

ORE FEED 4X2 Kingston

Date: 11/03/76

Pounds Feed	Operating Start	Operating Stop	Product Weight C1	Product Weight C2	Product Weight T2	1st Pass - Sorter Remarks	Min
619	1325	1332				1 Nov.	
610	1348	1355					
1229	1402	1403	638				
	1405	1418					
625	1500	1538					
618	1540	1545					
630	1548	1607	645				90
604							
2477							
279	0913	0950				3 Nov. - instability	
638	0954	1015	655			fill hopper	
632	1023	1110				put in relay - coil hot	
665							
2214	1330	1335					
645	1345	1420				fill hopper - instability	
626	1345	1428				coil heating	
610	1431	1437				coil heating	
	1440	1455				fill hopper	
604	1510	1610	669				
596							
592							
1792							229
							319

ORE FEED 4X2 Kingston

Date: 11/04/76

Pounds Feed	Operating Start	Operating Stop	Product Weight C1	Product Weight C2	Product Weight T2	1st Pass - Sorter Remarks	Min
612	0832	0916	643			install I-Tube on deflector gate	
530							
620							
1762							
655	0925	1000				solenoid smoking	
600	1030	1035				solenoid smoking	
641							
1896						new coil ordered	84
639	0912	0918	690			8 Nov. fill hopper	
653	0930	1006					
636	1013	1022					
1928							
623	1038	1116	668			fill hopper	89
620							
653							
1896							
638	1120	1159	674			fill hopper	
664							
637							
1939							

ORE FEED 4X2 Kingston Date: 11/08/76

Pounds Feed	Operating Start	Operating Stop	Product Weight C1	Product Weight C2	Product Weight T2	1st Pass - Sorter Remarks	Min
647	1205	1210				adjust coil and fill hopper	
640	1250	1327					
620			553				
1907							
643	1332					fill hopper	
643							
658		1407				fill hopper	
1944							
627	1412						
636			584				
652		1450				fill hopper	
1915							
668	1455						
653							
652		1535				fill hopper	
1973							
623	1540	1558				breaker kick out	
626	1605						
256							
1505		1615					222

ORE FEED 4X2 Kingston T-1 Date: 11/08/76

Pounds Feed	Operating Start	Operating Stop	Product Weight C1	Product Weight C2	Product Weight T2	2nd Pass - Sorter Remarks	Min
	1625				624	fill hopper	
					616		
		1713			613		
	1720				632	fill hopper	
					644		
		1806			625		
	1812				630	fill hopper	
					620		
		1950			630		
	1955			676	596	fill hopper	
					665		
		2035			644		
	2042				634	fill hopper	
					646		
		2130			622		
	2135				663	fill hopper	
					639		
		2216			638		
	2223			662	620	fill hopper	
					624		
		2307			635		
	2314				605	fill hopper	
					625		
		2356			629	end of shift	407

ORE FEED 4X2 Kingston T-1

Date: 11/09/76

Pounds Feed	Operating Start	Operating Stop	Product Weight C_1	Product Weight C_2	Product Weight T_2	2nd Pass - Sorter Remarks	Min
	0812				653	fill hopper	
					635		
		0855			673		
	0900				657		
					633		
		0945		650	669		
	0952				639		
		1025		392	382		121
				2380	20060		528
577						Kingston 2X1 pass 1	
599						sensitivity set @ 4 MV	
530						reconstructed to isolate coil from conveyor	
1706							
572						scrub unstable at 6 MV	
519							
520							
1611							

ORE FEED 4X2 Champion Date: 11/18/76

Pounds Feed	Operating Start	Operating Stop	Product Weight C_1	Product Weight C_2	Product Weight T_2	1st Pass - Sorter Remarks	Min
586	0900	0930				belt cut - rock underneath	
539							
538	0942	0945					
1663						fill hopper	
596	0950	1012				adjust vibrations (sorter)	
576	1017						
589		1034					
1761						fill hopper	
624	1038						
615							
583		1113					
1822			638			fill hopper	
630	1121						
588							
584							
345		1201					
2147						fill hopper	
552	1205						
569							
594		1240					
1715			618			fill hopper	182

ORE FEED 4X2 Champion Date: 12/18/76

Pounds Feed	Operating Start	Operating Stop	Product Weight C1	Product Weight C2	Product Weight T2	1st Pass - Sorter Remarks	Min
564	1243						
583							
616		1317					
1763							
528	1321						
543							
584		1352					
1655			646				
600	1356						
594							
588		1432					
1782							
562	1438						
587							
582							
546		1525	136				
2277							330

16585/330 = 50.26 #/min
3015 #/hr

ORE FEED 4X2 Champion T_1 Date: 11/19/76

Pounds Feed	Operating Start	Operating Stop	Product Weight C_1	Product Weight C_2	Product Weight T_2	2nd Pass - Sorter Remarks	Min
	1534				616		
					638	Nov. 18	
		1615			646		223
	0811				654		
					634		
		0859			677		
	0903				649		
					661		
		0948			625		
	0952				645		
					687		
		1035			681		
	1040				702		
					676		
		1118			689		
	1123				705		
					670	# % Wt.	
		1207			659	C_1 2038 12.55	
	1215				637	C_2 660 4.06	
					627	T_2 13549 83.39	
		1305		660	371	16247 100.00	
				660	13549		309

14209/309 = 45.98 x 60 = 2759 #/hr

ORE FEED 4X2 Centennial Date: 11/30/76

Pounds Feed	Operating Start	Operating Stop	Product Weight C_1	Product Weight C_2	Product Weight T_2	1st Pass - Sorter Remarks	Min
537	0830	0850				repair feeder	
545	0858						
525		0924					
1607							
536	0930		556				
528							
526		1001					
1590							
549	1008						
559			570				
541		1046					
1649							
492	1055						
519			528				
515							
325		1123					
1851							
551	1130						
491			560				
532		1209					
1574							182

ORE FEED 4X2 Centennial Date: 11/30/76

Pounds Feed	Operating Start	Operating Stop	Product Weight C1	Product Weight C2	Product Weight T2	1st Pass - Sorter Remarks	Min
521	1217						
510							
509							
532		1255	556				
2072							
578	1303						
564							
599		1310	576			switch burn out on vibrator	
1741							
533	1331						
511							
568							
585		1405	580				
2197							
557	1412						
505							
541							
549		1452	596				
2152							
586	1458						
560							
559							
466		1536	599				
2171							339

ORE FEED 4X2 Centennial Date: 11/30/76

Pounds Feed	Operating Start	Operating Stop	Product Weight C_1	Product Weight C_2	Product Weight T_2	1st Pass - Sorter Remarks	Min
572	1543		572				
542							
537							
542		1635					
2193							
556	1641		588				
525							
532		1720					
1613							
598	1725						
527							
547		1812	578				
1672							
			6859				477

24082/477 = 50.49 #/min, 3029 #/hr

ORE FEED 4X2 Centennial Date: 11/30/76

Pounds Feed	Operating Start	Operating Stop	Product Weight C_1	Product Weight C_2	Product Weight T_2	2nd Pass - Sorter Remarks	Min
	1820	1902			609		
	1910	2003			593		
	2009	2054			605		
					614		
	2059	2116			608		
					604		
	2122	2143		596	616		
	2148				638		
					631		
		2234			605		
	2239				600	16899/399 = 42.35 #/min 2541 #/hr	
					594		
		2325			632		
	2331				627		
					629		
					609		
		2358		600	598		
	0810				615	Dec. 1 VM here to adjust for 2X1 fraction	
					613		
		0826			603		
	0830				598		
					566		
		0907			599		
	0916				568		
		1005		508	621		

	Wt.	% Wt.
	215	
C_1	6859	29.51
C_2	1704	7.11
T_2	15195	63.38
	23973	

ORE FEED 2X1 Centennial Date: 12/02/76

Pounds Feed	Operating Start	Operating Stop	Product Weight C1	Product Weight C2	Product Weight T2	1st Pass - Sorter Remarks	Min
553	1049	1051					
556	1115						
584		1420					
1693						fill hopper	
546	1430						
398			588				
559							
554							
2057		1730				VM & I till 530	
620	0814		650			Dec. 3	
716		0857					
640	0904						
276		1240				Adjust belt - 6 MV setting - rock in belt disturbed setting	
118	1254	1430	414				
2370							
							1042
6120			1652				

6120/1042 = 5.87 #/hr
352 #/hr

ORE FEED 2X1 Centennial Date: 12/03/76

Pounds Feed	Operating Start	Operating Stop	Product Weight C_1	Product Weight C_2	Product Weight T_2	2nd Pass - Sorter Remarks	Min
	1451	1552				door opened - gates wild	
	0833					Dec. 6	
					633	T_2 @ 0930	
		1118			612	T_2 @ 1145	
	1126					fill hopper	
					655	T_2 @ 1230	
					643	T_2 @ 1402	
		1615			655	T_2 @ 1530	
	0808	0825		589	551	Dec. 7	
				589	3749		532

	Wt.	% Wt.
C_1	1652	27.58
C_2	589	9.83
T_2	3749	62.59
	5990	100.00

4338/532 = 8.15 #/min
489.25 #/hr

ORE FEED 2X1 Kingston | Date: 12/07/76

Pounds Feed	Operating Start	Operating Stop	Product Weight C_1	Product Weight C_2	Product Weight T_2	1st Pass - Sorter Remarks	Min
479	0915	0941					
571	0944	1115					
519	1154	1255				rock in belt - adj. vibrator	
519	1307	1442	576			conc @ 1340 fill hopper	
2088	1450						
549							
674		1615				shift stop @ 4:15 pm	298
529	0810					Dec. 8	
506		1040	581			conc @ 9:10 am	
2258	1101	1233				fill hopper	
552	1245					conc @ 1410	
557		1445				freight - door opened - gate upset	
545	1454						
486		1615				shift stop @ 4:15 p.m.	
2140							
	0802	0930	556			Dec. 9 - 1st pass completed	
							531

6486/829 = 7.82 #/min
469 #/hr

ORE FEED 2X1 Kingston

Date: 12/09/76

Pounds Feed	Operating Start	Operating Stop	Product Weight C_1	Product Weight C_2	Product Weight T_2	2nd Pass - Sorter Remarks	Min
	0945						
		1350					
	1352	1354			643	T2 @ 11:20 a.m.	
	1355	1401					
	1410	1425			651	T_2 @ 12:55	
	1445	1520					
	1525	1615			625	fill hopper T @ 1510	
	0815	0842				Dec. 10	
	0847				634	@ 9:00 a.m.	
					617	@ 10:15 a.m.	
		1115		405	446	@ 11:15 a.m.	468

	Wt.	% Wt.
C_1	2313	36.52
C_2	405	6.39
T_2	3616	57.09
	6334	100.00

4021/468 = 8.59 #/min
515 #/hr

12/10/76
12/13/76
Date: 12/14/76

ORE FEED 2X1 Champion

Pounds Feed	Operating Start	Operating Stop	Product Weight C_1	Product Weight C_2	Product Weight T_2	1st Pass - Sorter Remarks	Min
587	1210	1215				adjust	
596	1230	1305				adjust	
585	1308						
614							
2382		1615				fill hopper	
589	0822					Dec. 13 adjust	
617						T_1 @ 0930	
618		1210				T_1 @ 1110 adjust 10'	
1824							
284	1220	1320				T_1 @ 1258	
595	1329						
624						T_1 @ 1505	
612		1505	777				
2115	0815	0820				Dec. 14 adjust	
298	0825	1035	18			@ 10:30 a.m.	626
6619			795				

6619/626 = 10.57 #/min
634 #/hr

ORE FEED 2X1 Champion Date: 12/10/76

Pounds Feed	Operating Start	Operating Stop	Product Weight C_1	Product Weight C_2	Product Weight T_2	2nd Pass - Sorter Remarks	Min
	1045						
					683	T_2 @ 1233	
					671	T_2 @ 1410	
		1528			662	T_2 @ 1543 fill hopper	
	1535	1615					
	0803	0805				Dec. 15 adjust	
	0828	0832				adjust	
	0837	0839				adjust	
	0851					adjust	
					682	T_2 @ 0950	
					685	T_2 @ 1122	
					714	T_2 @ 1205	
		1518			684	T_2 @ 1430 door opened @ 1518	
	0814	0816				Dec. 16 adjust	
	0819	0844					
	0903	0906		124	666		688
						5571/688 = 8.10 #/min 486 #/hr	
				124	5447		

APPENDIX B

In determining the economic feasibility of sorting versus conventional methods of producing a copper concentrate, the evaluation utilized a cash flow approach assuming the investment made in mining, sorting, milling and concentrating would be revenue expansion. The cash flow technique refers to cash revenues minus cash expenses. Cash flows were used because it avoids the ambiguities of accounting measures and is theoretically a better measurement of the net economic benefits associated with a prospective project.

The Cash Flow Computer Program

A computer program developed by the Bureau of Mines was used to calculate the net cash flows[1]. The program was originally designed to analyze the economic feasibility of a mineral deposit under uncertainty, but allows the user to select a point estimate over the life of the project. This option is equivalent to certainty analysis and removes any ambiguities associated with various estimates when uncertainty is incorporated into the model. The program requires various estimates of parameters such as ore grade, recovery, tonnage, capital investments in mining and processing, working capital, operating capital and property value. The program utilizes the input data to calculate the cash flows after taxes which equal cash flow before taxes minus taxes. The investment tax credit, property taxes, state and federal taxes are included in the cash flow analysis. The cash flows in year t are:

$$\text{Cash}_t = \text{Total Income} + \text{Depreciation} - \text{Federal Taxes} - \text{Operating Expenses} + \text{Working Capital}$$

The cash flows are initially adjusted for property value and terminally adjusted for salvage value of depreciable assets plus cumulative working capital. Local and state taxes are subtracted from income.

Michigan Single Business Tax

Because of the pecularities of our tax system, it is not possible to develop a general cash flow program (which accounts for local and state taxes). The Bureau of Mines program was modified to accomodate the Michigan Single Business Tax which became effective January 1, 1976. It replaces several state taxes including the tax on corporate profits. It was designed to increase capital investment in the state and stabilize tax revenues.

There are several variations of the tax depending on earnings before Federal taxes (EBFT), sales, or the degree of labor intensity of the firm. There are five methods to calculate the firm's tax liability. All five forms of the tax were calculated in the program and the minimum value was selected as required by law. The single business tax is calculated as follows(2):

SBT1 = 0.0235 (EBFT + L + 0.72 D + I - c)

where EBFT= profits before Federal taxes

L = total labor compensation

D = allowable depreciation

I = interest expense

C = cost of newly acquired capital

SBT2 = 0 if EBFT $\leq$ \$34,000

SBT3 = .0235 (SBT1 -(34,000 -2(EBFT -34,000)) for 34,000 $<$ sales $<$ \$51,000

SBT4 = .0235 * 0.5 * Sales

SBT5 = 0.0235 *(TB - ((L/EBFT + L + D + I) + 0.65) *TB))

where TB = (EBFT + L $\pm$ I + D - C)

the State tax is then

STAX = min (SBT1, SBT2, SBT3, SBT4, SBT5)

The single business tax for Michigan will effect the investment strategy for mining firms. The tax favors firms which have intensive and frequent capital investment such as the automobile firms. Since mining does not fall into this category, the cash flow after taxes may be reduced as compared to the previous tax structure in Michigan.

Rate-of-Return on the Cash Flows

In order to determine the feasibility of the project, the cash flows of the project should be compared given the opportunity cost of funds; i.e., the alternative of investing the funds in some other project such as government bonds, or some other capital project. The opportunity cost of funds is usually expressed in the firm's cost-of-capital. Since this feasibility study was developed for a hypothetical firm, it is not practical to estimate a cost-of-capital for a firm.

An alternative to the cost-of-capital approach is to utilize the rate-of-return (ROR) on the investment which in this study is the internal-rate-of-return. This is the rate which equates the discounted cash flows after taxes to the initial capital outlay of the project. Project feasibility is ranked by the ROR on investment. The higher the ROR on the project, the more favorable this project becomes as compared to other projects with a lower ROR assuming some minimal rate the firm is willing to accept.

(1) Harold J. Bennett and Lawrence E. Welborn, "Application of Sensitivity and Probabilistic Analysis Methods to Mineral Deposit Evaluation".

(2) James R. Gale, "A Note on the Single Business Tax in Michigan", Bureau of Industrial Development, Michigan Technological University (1977).