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CONCENTRATION OF URANIUM MINERALS FROM CANADIAN ORES BY MAGNETIC MEANS

F. H. HARTMAN AND R. A. WYMAN

MINERAL PROCESSING DIVISION

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CONCENTRATION OF URANIUM MINERALS FROM CANADIAN ORES BY MAGNETIC MEANS

by

F.H. Hartman* and R.A. Wyman**

ABSTRACT

Because previous work with a Jones Wet Magnetic Mineral Separator demonstrated the possibility of concentrating certain uranium minerals by this means, a more extensive examination was undertaken. Ores from three areas, viz. Bancroft (one mine), Beaverlodge (two mines) and Elliot Lake (three mines), were investigated, using a number of experimental conditions and procedures, with results as summarized below:

Best Over-all Results

Mine	Magnetic Concentrate			No. of Passes
	Recovery %	Weight %	U_3O_8 %	
Denison	87	27	0.45	12
Rio Algom (Nordic)	86	15	0.44	10
Eldorado (Beaverlodge)	82	52	0.34	10
Canada-Met	99	85	0.28	6
Faraday	56	25	0.25	3*
Gunnar	No concentration was achieved.			

*Screen fractions

Best Single-Pass Results

Mine	Magnetic Concentrate		
	Recovery %	Weight %	U_3O_8 %
Denison	71	7	1.19
Rio Algom (Nordic)	68	5	1.14
Eldorado (Beaverlodge)	50	24	0.44
Canada Met	95	73	0.31

*Research Scientist and **Head, Industrial Minerals Milling Section, Mineral Processing Division, Mines Branch, Department of Energy, Mines, and Resources, Ottawa, Canada.

Direction des mines

Bulletin technique TB-118

CONCENTRATION DES MINÉRAUX URANIFÈRES À PARTIR DES MINERAIS CANADIENS PAR LE PROCÉDÉ MAGNÉTIQUE

par

F.H. Hartman* et R.A. Wyman**

RÉSUMÉ

Sur la base d'un travail antérieur effectué avec le Séparateur Magnétique Jones par voie humide, la possibilité de concentration de certains minéraux uranifères par ce moyen a été démontrée et un examen plus approfondi a été entrepris. Les minerais de trois régions, c'est-à-dire de Bancroft (une mine), de Beaverlodge (deux mines) et du Lac Elliot (trois mines), ont été étudiés dans des conditions expérimentales et par des méthodes différentes dont les résultats sont résumés ci-dessous:

Meilleurs Résultats Totaux

Mine	Concentré Magnétique			Nb de passages
	Rendement %	Poids %	U_3O_8 %	
Denison	87	27	0.45	12
Rio Algom (Nordic)	86	15	0.44	10
Eldorado (Beaverlodge)	82	52	0.34	10
Canada-Met	99	85	0.28	6
Faraday	56	25	0.25	3*
Gunnar	Pas de concentration obtenue			

*Parties tamisées

Meilleurs Résultats d'un Seul Passage

Mine	Concentré Magnétique		
	Rendement %	Poids %	U_3O_8 %
Denison	71	7	1.19
Rio Algom (Nordic)	68	5	1.14
Eldorado (Beaverlodge)	50	24	0.44
Canada-Met	95	73	0.31

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CONTENTS

TABLES

INTRODUCTION

During the Mines Branch investigation into the use of the Jones wet magnetic separator (1), it was observed (a) that certain uranium minerals, brannerite, uraninite and monazite were concentrated in the magnetics and (b) that a weathered pegmatite ore containing uraninite and uranothorite showed some concentration. It was thought worthwhile to explore, in more detail, this possible means of beneficiation.

Ores from three main areas of uranium mining in Canada, including some samples on hand from non-operating mines, were investigated, viz., Beaverlodge (Gunnar, Eldorado), Elliot Lake (Rio Algom's Nordic, Denison, Can-Met), and Bancroft (Faraday).

DESCRIPTION OF SAMPLES

All but one of the samples were obtained from the Extraction Metallurgy Division of the Mines Branch; they may be described as follows, according to Company and mine of origin:

1. Gunnar Gold Mines Limited, later Gunnar Mines Limited, now merged into Gunnar Mining Limited. The sample was collected in 1953 from the Company's mine at Beaverlodge, Saskatchewan. The principal uranium minerals are pitchblende and uraninite.

2. Eldorado Mining and Refining Limited, Beaverlodge Mine, Saskatchewan. The sample was the minus 10-mesh discharge from the autogeneous mill in 1966. In general, ore from the mine is similar to Gunnar. The principal uranium minerals are pitchblende and uraninite.

3. Faraday Uranium Mines Limited, Bancroft, Ontario, later the Canadian Faraday Corporation Limited, now part of Consolidated Canadian Faraday Limited. This wet sample, taken in 1961, came from the classifier overflow in the grinding circuit. The ore is pegmatitic with uraninite and uranothorite as the principal uranium minerals.

4. Denison Mines Limited, Elliot Lake, Ontario. Three samples were obtained:

a) Wet classifier overflow - collected in 1961
b) Dry mill feed - collected in 1963
c) Dry ore - collected in 1968.

These are typical Elliot Lake conglomerates. The uranium minerals are chiefly brannerite with lesser amounts of uraninite.

5. Can-Met Explorations Limited, now part of Denison Mines Limited, Elliot Lake, Ontario. The sample was taken in 1959 and contained dark material, probably from the diabase dyke.

6. Rio Algom Mines Limited, Nordic Mine, Elliot Lake, Ontario. This sample was on hand, taken probably in 1967. The ore is a conglomerate with brannerite and uraninite being the main uranium minerals.

EXPERIMENTAL WORK AND RESULTS

For comparison of the response of the various samples to treatment, three series of experiments were conducted using feed that was:

(A) - Passed three times through the Jones separator equipped with salient-pole plates at 25 amperes. The magnetic products were combined.

(B) - Sized into plus 150-, 150- to 325-, and minus 325-mesh fractions and each fraction was passed three times through the Jones separator equipped with salient-pole plates at 25 amperes. For each fraction, the magnetic products from the three passes were combined.

(C) - Passed 10 times through the Jones separator at 25 amperes with (a) salient-pole plates and (b) high-intensity plates.

Comparison of these results indicated that Elliot Lake ores were the most amenable to magnetic treatment; therefore, a more extensive investigation was carried out on them (Treatments 1, 2, and 3).

Many and various experiments were performed, but only significant results are reported.

1. Gunnar Gold Mines Limited

1.0 Sample Preparation. The head sample was ground in an Abbé mill at 50% solids for 45 minutes. Screen analysis of the product is shown in Table 1.

TABLE 1

Screen Analysis of Ground Ore, Gunnar Gold Mines Limited

Fraction mesh (Tyler)*	Weight %
+ 65	4.8
-65 + 100	1.6
-100 + 150	7.3
-150 +200	8.8
-200 +325	19.3
-325	58.2
Total	100.0

*Tyler series used throughout.

1.0.1 Series A, Salient-Pole Plates

The results are given in Table 2.

TABLE 2

Magnetic Separation (Jones), Salient-Pole Plates, Gunnar Gold Mines Limited

Product	Weight %	U_3O_8 %	Distribution %
Mags, 25 amp, 3 passes	11.7	0.18	11.7
Non-mags	88.3	0.18	88.3
Feed (calcd)	100.0	0.18	100.0

1.0.2 Series B, Salient-Pole Plates

Table 3 shows the results obtained.

TABLE 3

Magnetic Separation (Jones), Salient-Pole Plates, Gunnar Gold Mines Limited, Screen Fractions

Product	Weight %		U_3O_8 %	Distribution %	
	Test	Over-all		Test	Over-all
+150 mesh, Mags, 25 amp, 3 passes	11.3	2.2	0.09	10.7	1.0
Non-mags	88.7	17.4	0.09	89.3	8.9
Sub-total	100.0	19.6	0.09	100.0	9.9
150 to 325 mesh, Mags, 25 amp, 3 passes	13.4	4.4	0.14	16.4	3.5
Non-mags	86.6	28.4	0.11	83.6	17.7
Sub-total	100.0	32.8	0.12	100.0	21.2
-325 mesh, Mags, 25 amp, 3 passes	9.5	4.5	0.23	8.5	5.9
Non-mags	90.5	43.1	0.26	91.5	63.0
Sub-total	100.0	47.6	0.25	100.0	68.9
Feed (calcd)	-	100.0	0.18	-	100.0

2. Eldorado Mining and Refining Limited, Beaverlodge Mine

2.0 Sample Preparation

The minus 10-mesh discharge from the autogenous mill was ground at 50% solids for 45 minutes in an Abbé mill. The screen analysis of the product is given in Table 4.

TABLE 4

Screen Analysis of Ground Ore,
Eldorado Mining and Refining Limited

Fraction mesh	Weight %
+ 65	0.7
-65 +100	1.6
-100 +150	7.6
-150 +200	8.6
-200 +325	18.8
-325	62.7
Total	100.0

2.0.1 Series A, Salient-Pole Plates

The results are given in Table 5.

TABLE 5

Magnetic Separation (Jones), Salient-Pole Plates,
Eldorado Mining and Refining Limited

Product	Weight %	U_3O_8 %	Distribution %
Mags, 25 amp, 3 passes	21.2	0.59	59.0
Non-mags	78.8	0.11	41.0
Feed (calcd)	100.0	0.21	100.0

2.0.2 Series B, Salient-Pole Plates

The results are shown in Table 6.

TABLE 6

Magnetic Separation (Jones), Salient-Pole Plates, Eldorado Mining and Refining Limited, Screen Fractions

Product	Weight %		U_3O_8 %	Distribution %	
	Test	Over-all		Test	Over-all
+150 mesh, Mags, 25 amp, 3 passes	34.6	7.1	0.38	84.0	12.5
Non-mags	65.4	13.6	0.04	16.0	2.3
Sub-total	100.0	20.7	0.16	100.0	14.8
150 to 325 mesh, Mags, 25 amp, 3 passes	33.4	8.4	0.60	87.3	23.5
Non-mags	66.6	16.8	0.04	12.7	3.4
Sub-total	100.0	25.2	0.23	100.0	26.9
-325 mesh, Mags, 25 amp, 3 passes	15.8	8.6	0.66	45.3	26.5
Non-mags	84.2	45.5	0.15	54.7	31.8
Sub-total	100.0	54.1	0.23	100.0	58.3
Feed (calcd)	-	100.0	0.22	-	100.0

2.0.3 Series C, High-Intensity Plates

The results are shown in Table 7.

TABLE 7

Magnetic Separation (Jones), 10 Passes, High-Intensity Plates, Eldorado Mining and Refining Limited, 45-min Grind

Product	Weight %	U_3O_8 %	Distribution %
Pass 1, mags	24.2	0.44	49.6
Pass 2, "	10.9	0.33	16.7
Pass 3, "	4.1	0.22	4.2
Pass 4, "	3.0	0.22	3.1
Pass 5, "	2.1	0.20	2.0
Pass 6, "	2.0	0.18	1.7
Pass 7, "	1.7	0.17	1.4
Pass 8, "	1.5	0.16	1.1
Pass 9, "	1.3	0.16	1.0
Pass 10, "	1.2	0.13	0.7
Pass 10, non-mags	48.0	0.08	18.5
Feed (calcd)	100.0	0.22	100.0
Feed (assay)	-	0.22	-

3. Faraday Uranium Mines Limited

3.0 Sample Preparation

The classifier overflow sample was used as received. The screen analysis is given in Table 8.

TABLE 8

Screen Analysis, Classifier Overflow, Faraday Uranium Mines Limited

Fraction Mesh	Weight %
+ 65	1.2
-65 +100	5.3
-100 +150	12.9
-150 +200	14.4
-200 +325	18.9
-325	47.2
Total	100.0

3.0.1 Series A, Salient-Pole Plates

The results are shown in Table 9.

TABLE 9

Magnetic Separation (Jones), Salient-Pole Plates, Faraday Uranium Mines Limited

Product	Weight %	U_3O_8 %	Distribution %
Mags, 25 amp, 3 passes	24.5	0.25	45.1
Non-mags	75.5	0.07	54.9
Feed (calcd)	100.0	0.11	100.0

3.0.2 Series B, Salient-Pole Plates

The results are given in Table 10.

TABLE 10

Magnetic Separation (Jones), Salient-Pole Plates, Faraday Uranium Mines Limited, Screen Fractions

Product	Weight %		U_3O_8 %	Distribution %	
	Test	Over-all		Test	Over-all
+150 mesh, Mags, 25 amp, 3 passes	22.0	6.3	0.05	59.9	3.0
Non-mags	78.0	22.4	0.01	40.1	2.0
Sub-total	100.0	28.7	0.02	100.0	5.0
150 to 325 mesh, Mags, 25 amp, 3 passes	30.0	9.0	0.18	76.3	14.7
Non-mags	70.0	20.8	0.02	23.7	4.3
Sub-total	100.0	29.8	0.07	100.0	19.0
-325 mesh, Mags, 25 amp, 3 passes	23.5	9.7	0.44	51.5	38.5
Non-mags	76.5	31.8	0.13	48.5	37.5
Sub-total	100.0	41.5	0.21	100.0	76.0
Feed (calcd)	-	100.0	0.11	-	100.0

4. Denison Mines Limited

4.0 Sample Preparation

The wet sample of classifier overflow was used as received. The screen analysis is given in Table 11.

TABLE 11

Screen Analysis, Classifier Overflow, Denison Mines Limited

Fraction mesh	Weight %
+ 65	6.2
-65 +100	14.9
-100 +150	17.2
-150 +200	13.2
-200 +325	13.4
-325	35.1
Total	100.0

4.0.1 Series A, Salient-Pole Plates

The results are given in Table 12.

TABLE 12

Magnetic Separation (Jones), Salient-Pole Plates, Denison Mines Limited, Classifier Overflow

Product	Weight %	U_3O_8 %	Distribution %
Mags, 25 amp, 3 passes	5.3	2.37	68.9
Non-mags	94.7	0.06	31.1
Feed (calcd)	100.0	0.18	100.0

4.0.2 Series B, Salient-Pole Plates

The results are given in Table 13.

TABLE 13

Magnetic Separation (Jones), Salient-Pole Plates, Denison Mines Limited, Screen Fractions, Classifier Overflow

Product	Weight %		U_3O_8 %	Distribution %	
	Test	Over-all		Test	Over-all
+150 mesh, Mags, 25 amp, 3 passes	4.9	2.2	1.22	71.5	14.0
Non-mags	95.1	42.5	0.03	28.5	5.6
Sub-total	100.0	44.7	0.08	100.0	19.6
150 to 325 mesh, Mags, 25 amp, 3 passes	7.9	1.9	3.15	90.6	31.2
Non-mags	92.1	21.8	0.03	9.4	3.1
Sub-total	100.0	23.7	0.28	100.0	34.3
-325 mesh, Mags, 25 amp, 3 passes	5.3	1.7	2.74	52.0	24.3
Non-mags	94.7	29.9	0.14	48.0	21.8
Sub-total	100.0	31.6	0.27	100.0	46.1
Feed (calcd)	-	100.0	0.19	-	100.0

4.0.3 Series C (b), High-Intensity Plates

The results are shown in Table 14.

TABLE 14

Magnetic Separation (Jones), 10 Passes, High-Intensity Plates, Denison Mines Limited, Classifier Overflow

Product	Weight %	U_3O_8 %	Distribution %
Pass 1, mags	3.1	1.25	46.9
Pass 2, "	1.7	0.45	9.3
Pass 3, "	1.4	0.26	4.4
Pass 4, "	1.3	0.19	3.0
Pass 5, "	1.2	0.15	2.2
Pass 6, "	1.0	0.11	1.4
Pass 7, "	1.1	0.10	1.3
Pass 8, "	1.0	0.08	1.1
Pass 9, "	1.1	0.08	1.1
Pass 10, "	1.0	0.07	0.7
Pass 10, non-mags	86.1	0.03	28.6
Feed (calcd)	100.0	0.08 *	100.0

*This is low because the feed had remained for a long period of time as a pulp and some uranium could have been lost in solution.

4.0.4 Treatment 1

The plus 150-mesh fraction of the classifier overflow sample was passed three times at 25 amperes through the Jones separator equipped with salient-pole plates. The non-magnetic product was then stage-ground with screening to minus 150 mesh and combined with the original minus 150-mesh fraction, which was screened into plus and minus 325-mesh portions. These were each passed three times at 25 amperes through the Jones separator equipped with salient-pole plates -- no wash water was used with the minus 325-mesh fraction. The non-magnetic product from the minus 325-mesh portion was passed three times at 25 amperes through the Jones separator equipped with high-intensity plates -- wash water was used. The results are shown in Table 15.

TABLE 15

Magnetic Separation (Jones),
Denison Mines Limited, Screen Fractions, Classifier Overflow

Product	Weight %		U_3O_8	Distribution %	
	Test	Over-all	%	Test	Over-all
+150 mesh, Mags, 25 amp, 3 passes	6.8	3.3	1.46	49.0	26.4
150 to 325 mesh, Mags, 25 amp, 3 passes	5.5	2.7	1.58	43.5	23.3
Non-mags	87.7	42.9	0.02	7.5	4.0
Sub-total	100.0	48.9	0.21	100.0	53.7
-325 mesh Mags, 25 amp, 3 passes (Salient-Pole Plates)	13.0	6.6	0.69	53.6	24.8
Mags, 25 amp, 3 passes (High-intensity Plates)	7.4	3.8	0.24	10.7	5.0
Non-mags	79.6	40.7	0.07	35.7	16.5
Sub-total	100.0	51.1	0.17	100.0	46.3
Feed (calcd)	-	100.0	0.18	-	100.0

4.1.1 Treatment 2 (a).

This was a multi-stage separation of the dry head sample, using salient-pole plates, beginning with minus 28-mesh material and incorporating a grinding stage between successive magnetic separations.

Step 1. The feed was passed three times at 25 amperes through the Jones separator.

Step 2. The non-magnetic product was wet-ground for 10 minutes at 50% solids in an Abbé mill charged with 1.3-cm Burundum cylinders. The milled product was again passed three times through the Jones separator.

Steps 3 - 10. These are the same as Step 2.

The results are given in Table 16.

TABLE 16

Magnetic Separation (Jones), Stage Grinding, Salient-Pole Plates, Denison Mines Limited, Feed minus 28-mesh

Product	Weight %	U_3O_8 %	Distribution %
Step 1, mags	3.2	1.68	42.6
Step 2, "	3.4	0.84	22.8
Step 3, "	1.6	0.49	6.3
Step 4, "	1.1	0.33	2.9
Step 5, "	1.2	0.24	2.3
Step 6, "	1.3	0.15	1.6
Step 7, "	1.7	0.13	1.8
Step 8, "	1.2	0.09	0.9
Step 9, "	1.3	0.09	0.9
Step 10, "	1.3	0.07	0.7
Step 10, non-mags	82.7	0.03	17.2
Feed (calcd)	100.0	0.13	100.0
Feed (assay)	-	0.17	-

4.1.2 Treatment 2 (b)

This was a repeat of 4.1.1 treatment 2 (a), but using high-intensity plates. The multi-stage treatment was carried on for 12 steps. The results are given in Table 17.

TABLE 17

Magnetic Separation (Jones), Stage Grinding, High-Intensity Plates, Denison Mines Limited, Feed minus 28-mesh

Product	Weight %	U_3O_8 %	Distribution %
Step 1, mags	5.8	1.21	58.9
Step 2, "	2.0	0.86	14.4
Step 3, "	1.1	0.41	3.8
Step 4, "	1.0	0.23	1.9
Step 5, "	1.5	0.15	1.9
Step 6, "	1.1	0.10	0.9
Step 7, "	0.9	0.09	0.7
Step 8, "	1.2	0.07	0.7
Step 9, "	0.8	0.06	0.4
Step 10, "	0.7	0.06	0.3
Step 11, "	1.0	0.06	0.5
Step 12, "	0.9	0.05	0.4
Step 12, non-mags	82.0	0.02	15.2
Feed (calcd)	100.0	0.12	100.0

4.1.3 Treatment 2 (c)

The head sample was reduced dry to minus 48 mesh and the product was treated as in 4.1.2 Treatment 2 (b). The results are shown in Table 18.

TABLE 18

Magnetic Separation (Jones), Stage Grinding, High-Intensity Plates, Denison Mines Limited, Feed minus 48-mesh

Product	Weight %	U_3O_8 %	Distribution %
Step 1, mags	7.0	1.19	70.5
Step 2, "	2.8	0.33	7.6
Step 3, "	2.0	0.15	2.5
Step 4, "	1.8	0.10	1.7
Step 5, "	1.8	0.07	0.8
Step 6, "	1.3	0.07	0.8
Step 7, "	1.1	0.07	0.7
Step 8, "	1.0	0.06	0.5
Step 9, "	1.1	0.06	0.5
Step 10, "	0.8	0.06	0.3
Step 11, "	0.7	0.05	0.3
Step 12, "	1.0	0.05	0.4
Step 12, non-mags	77.6	0.02	13.4
Feed (calcd)	100.0	0.12	100.0

4.1.4 Treatment 2 (d)

The head sample was reduced dry to minus 65 mesh and treated as in 4.1.3 Treatment 2 (c).

The results are given in Table 19.

TABLE 19

Magnetic Separation (Jones), Stage Grinding, High-Intensity Plates, Denison Mines Limited, Feed minus 65-mesh

Product	Weight %	U_3O_8 %	Distribution %
Step 1, mags	6.2	1.59	69.3
Step 2, "	2.5	0.39	6.9
Step 3, "	1.7	0.14	1.7
Step 4, "	2.0	0.09	1.3
Step 5, "	2.4	0.09	1.8
Step 6, "	1.7	0.07	0.8
Step 7, "	1.4	0.06	0.6
Step 8, "	2.1	0.06	0.8
Step 9, "	1.5	0.05	0.5
Step 10, "	1.5	0.05	0.5
Step 11, "	2.0	0.04	0.6
Step 12, "	1.5	0.04	0.4
Build-up on plates, mags	0.9	0.31	12.0
Step 12, non-mags	72.5	0.03	12.8
Feed (calcd)	100.0	0.14	100.0

4.1.5 Treatment 2 (e)

The head sample was reduced dry to minus 100 mesh and the product treated as in 4.1.4 Treatment 2 (d).

The results are shown in Table 20.

TABLE 20

Magnetic Separation (Jones), Stage Grinding, High-Intensity Plates, Denison Mines Limited, Feed minus 100-mesh

Product	Weight %	U_3O_8 %	Distribution %
Step 1, mags	2.7	2.60	58.0
Step 2, "	2.8	0.69	16.0
Step 3, "	1.5	0.29	3.6
Step 4, "	1.1	0.19	1.8
Step 5, "	1.8	0.13	2.0
Step 6, "	1.1	0.11	1.0
Step 7, "	1.0	0.10	0.8
Step 8, "	1.4	0.09	1.1
Step 9, "	1.0	0.07	0.6
Step 10, "	0.8	0.06	0.4
Step 11, "	1.2	0.06	0.6
Step 12, "	1.0	0.05	0.4
Step 12, non-mags	82.6	0.02	13.7
Feed (calcd)	100.0	0.12	100.0

4.2.1 Series A, Modified (1)

Lump ore collected in 1968 was stage-crushed to minus 28 mesh. Three aliquots of this were separately ground for 15 minutes in an Abbé mill to the fineness shown in Table 21. One aliquot was passed once through the Jones separator, set at 25 amperes and equipped with salient-pole plates. The second aliquot was passed twice, and the third aliquot was passed three times, through the separator under the same conditions as the first aliquot.

The results are shown in Table 22.

TABLE 21

Screen Analysis, Ground Ore, 15-min Grind, Denison Mines Limited

Fraction mesh	Weight %
+35	0.1
-35 +48	1.3
-48 +65	6.3
-65 +100	16.7
-100 +150	20.0
-150 +200	9.9
-200 +325	12.1
-325	33.6
Total	100.0

TABLE 22

Magnetic Separation (Jones), 1, 2, 3 Passes, Salient-Pole Plates, Denison Mines Limited, Ground Ore, 15-min Grind

Number of Passes	Product	Weight %	U_3O_8 %	Distribution %
1	Mags, 25 amp	2.0	2.31	38.6
	Non-mags, 25 amp	98.0	0.08	61.4
	Total	100.0	0.12	100.0
2	Mags, 25 amp	2.6	2.33	47.8
	Non-mags, 25 amp	97.4	0.07	52.2
	Total	100.0	0.13	100.0
3	Mags, 25 amp	3.0	2.08	53.5
	Non-mags, 25 amp	97.0	0.06	46.5
	Total	100.0	0.12	100.0

4.2.2 Series A: Modified (2)

The same procedure as in 4.2.1 was followed, except the ore was ground for 30 minutes in the Abbé mill. Table 23 gives the screen analysis and Table 24 gives the results of the three magnetic separations at the finer grind.

TABLE 23

Screen Analysis, Ground Ore, 30-min Grind, Denison Mines Limited

Fraction mesh	Weight %
+ 48	tr
-48 + 65	0.4
-65 +100	3.5
-100 +150	12.4
-150 +200	12.6
-200 +325	20.7
-325	50.4
Total	100.0

TABLE 24

Magnetic Separation (Jones), 1, 2, 3 Passes, Salient-Pole Plates, Denison Mines Limited, Ground Ore, 30-min Grind

Number of Passes	Product	Weight %	U_3O_8 %	Distribution %
1	Mags, 25 amp	2.1	2.42	40.4
	Non-mags, 25 amp	97.9	0.08	59.6
	Total	100.0	0.13	100.0
2	Mags, 25 amp	2.4	2.61	50.8
	Non-mags, 25 amp	97.6	0.06	49.2
	Total	100.0	0.12	100.0
3	Mags, 25 amp	2.8	2.07	50.6
	Non-mags, 25 amp	97.2	0.06	49.4
	Total	100.0	0.11	100.0

5. Can-Met Explorations Limited

5.0 Treatment

Step 1. The head sample was reduced dry to minus 28 mesh and passed three times at 25 amperes through the Jones separator equipped with salient-pole plates.

Step 2. The non-magnetic product was ground for 10 minutes in an Abbé mill and again passed through the Jones separator.

Steps 3 to 6. These were repetitions of Step 2.

The results are given in Table 25.

TABLE 25

Magnetic Separation (Jones), Stage Grinding, Salient-Pole Plates, Can-Met Explorations Limited, Feed minus 28-mesh

Product	Weight %	U_3O_8 %	Distribution %
Step 1, mags	73.3	0.31	95.20
Step 2, "	4.4	0.19	3.50
Step 3, "	2.2	0.09	0.08
Step 4, "	1.8	0.05	0.04
Step 5, "	1.4	0.05	0.03
Step 6, "	1.7	0.04	0.03
Step 6, non-mags	15.2	0.02	1.12
Feed (calcd)	100.0	0.24	100.00

6. Rio Algom Mines Limited, Nordic Mine

6.0 Sample Preparation

Grinding tests were run in an Abbé mill, starting with minus 28-mesh feed, for 10, 20 and 30 minutes. The screen analyses of the products are shown in Table 26.

TABLE 26

Screen Analyses, Ground Ore,
Rio Algom Mines Limited, Nordic Mine

Fraction Mesh	Weight %		
	Time of Grind (min)		
	10	20	30
+ 65	16.7	2.5	0.2
-65 +100	19.0	9.6	1.8
-100 +150	14.4	15.4	8.5
-150 +200	9.4	14.2	9.9
-200 +325	11.3	17.5	19.8
-325	29.2	40.8	59.8
Total	100.0	100.0	100.0

6.0.1 Series A, Salient-Pole Plates

A sample, ground 30 minutes, was passed three times at 25 amperes through the Jones separator.

The results are given in Table 27.

TABLE 27

Magnetic Separation (Jones), Salient-Pole Plates,
Rio Algom Mines Limited, Nordic Mine, 30-min Grind

Product	Weight %	U_3O_8 %	Distribution %
Mags, 25 amp, 3 passes	4.3	1.04	61.5
Non-mags	95.7	0.03	38.5
Feed (calcd)	100.0	0.07	100.0

6.0.2 Series B, Salient-Pole Plates

A sample, ground for 30 minutes, was used for this test. The results are given in Table 28.

TABLE 28

Magnetic Separation (Jones), Salient-Pole Plates, Rio Algom Mines Limited, Nordic Mine, Screen Fractions

Product	Weight %		U_3O_8 %	Distribution %	
	Test	Over-all		Test	Over-all
+150 mesh Mags, 25 amp, 3 passes	5.7	1.1	0.58	68.6	10.9
Non-mags	94.3	14.8	0.02	31.4	5.0
Sub-total	100.0	15.9	0.05	100.0	15.9
150 to 325 mesh Mags, 25 amp, 3 passes	6.6	2.2	1.01	84.6	29.2
Non-mags	93.4	32.4	0.01	15.4	5.4
Sub-total	100.0	34.6	0.08	100.0	34.6
-325 mesh Mags, 25 amp, 3 passes	4.3	2.1	0.97	49.7	24.6
Non-mags	95.7	47.4	0.04	50.3	24.9
Sub-total	100.0	49.5	0.08	100.0	49.5
Feed (calcd)	-	100.0	0.08	-	100.0

6.0.3 Series C, Salient-Pole Plates

The minus 28-mesh head sample, after a 30-minute grind, was passed ten times at 25 amperes through the Jones separator.

The results are given in Table 29.

TABLE 29

Magnetic Separation (Jones), 10 Passes, Salient-Pole Plates, Rio Algom Mines Limited, Nordic Mine, 30-min Grind

Product	Weight %	U_3O_8 %	Distribution %
Pass 1, mags	2.1	1.72	48.8
Pass 2, "	0.8	0.90	9.2
Pass 3, "	0.7	0.51	4.5
Pass 4, "	0.7	0.36	3.2
Pass 5, "	0.7	0.25	2.1
Pass 6, "	0.9	0.17	2.0
Pass 7, "	0.9	0.15	1.7
Pass 8, "	0.9	0.13	1.6
Pass 9, "	0.5	0.10	0.8
Pass 10, "	0.5	0.10	0.7
Pass 10, non-mags	91.3	0.02	25.4
Feed (calcd)	100.0	0.08	100.0
Feed (assay)	-	0.07	-

6.0.4 Series C, High-Intensity Plates

The minus 28-mesh head sample, after a 30-minute grind, was passed through the Jones separator ten times at 25 amperes.

Table 30 gives the results obtained.

TABLE 30

Magnetic Separation (Jones), 10 Passes, High-Intensity Plates, Rio Algom Mines Limited, Nordic Mine, 30-min Grind

Product	Weight %	U_3O_8 %	Distribution %
Pass 1, mags	3.9	1.18	62.6
Pass 2, "	1.7	0.34	7.9
Pass 3, "	1.4	0.21	4.0
Pass 4, "	1.3	0.15	2.7
Pass 5, "	1.2	0.12	2.0
Pass 6, "	1.0	0.10	1.4
Pass 7, "	0.8	0.08	0.9
Pass 8, "	0.9	0.06	0.8
Pass 9, "	1.0	0.05	0.7
Pass 10, "	1.1	0.04	0.6
Pass 10, non-mags	85.7	0.01	16.4
Feed (calcd)	100.0	0.07	100.0
Feed (assay)	-	0.07	-

6.0.5 Series C, Modified, High-Intensity Plates

The minus 28-mesh head sample, after a 20-minute grind, was passed ten times through the Jones separator.

The results are shown in Table 31.

TABLE 31

Magnetic Separation (Jones), 10 Passes, High-Intensity Plates, Rio Algom Mines Limited, Nordic Mine, 20-min Grind

Product	Weight %	U_3O_8 %	Distribution %
Pass 1, mags	4.6	1.14	67.5
Pass 2, "	1.9	0.32	7.8
Pass 3, "	1.5	0.17	3.3
Pass 4, "	1.4	0.12	2.2
Pass 5, "	1.1	0.10	1.4
Pass 6, "	1.1	0.08	1.1
Pass 7, "	1.0	0.07	0.9
Pass 8, "	1.0	0.06	0.8
Pass 9, "	0.8	0.05	0.5
Pass 10, "	0.8	0.05	0.4
Pass 10, non-mags	84.8	0.01	14.1
Feed (calcd)	100.0	0.08	100.0
Feed (assay)	-	0.07	-

6.0.6 Series C, Modified, High-Intensity Plates

The minus 28-mesh head sample, after a 10-minute grind, was passed 10 times through the Jones separator.

The results are given in Table 32.

TABLE 32

Magnetic Separation (Jones), 10 Passes, High-Intensity Plates, Rio Algom Mines Limited, Nordic Mine, 10-min Grind

Product	Weight %	U_3O_8 %	Distribution %
Pass 1, mags	5.0	1.02	65.0
Pass 2, "	1.9	0.34	8.3
Pass 3, "	1.7	0.18	3.9
Pass 4, "	0.9	0.14	1.6
Pass 5, "	0.9	0.12	1.4
Pass 6, "	0.8	0.09	0.9
Pass 7, "	0.7	0.09	0.8
Pass 8, "	0.7	0.07	0.6
*Pass 9, "	0.7	0.06	0.5
*Pass 10, "	2.0	0.03	0.8
Pass 10, non-mags	84.7	0.02	16.2
Feed (calcd)	100.0	0.08	100.0
Feed (assay)	-	0.07	-

*During these runs, trouble was experienced with the mercury switch that supplies current to the coils.

7. Summary

Significant results, from all but Can-Met, are combined and tabulated in Table 33. Special treatment of Denison samples is shown in Table 34.

TABLE 33

Summary of Magnetic Separations

AREA	Bancroft	Beaverlodge		Elliot Lake	
MINE	Faraday	Gunnar	Eldorado	Denison	Nordic
FEED TYPE	Class. o'flow	Ore	Autogenous-mill discharge (-10 m)	Class. o'flow	Ore
Size mesh					
+ 65	1.2	4.8	0.7	6.2	0.2
-65 +100	5.3	1.6	1.6	14.9	1.8
-100 +150	12.9	7.3	7.6	17.2	8.5
-150 +200	14.4	8.8	8.6	13.2	9.9
-200 +325	18.9	19.3	18.8	13.4	19.8
-325	47.2	58.2	62.7	35.1	59.8
URANIUM MINERALS	Uraninite Uranothorite	Pitchblende Uraninite	Pitchblende Uraninite	Brannerite Uraninite	Brannerite Uraninite
BASE TYPE	Pegmatite	Pegmatite	Pegmatite	Conglomerate	Conglomerate
"A" Series: First 3 passes combined, 25 amp, salient plates.					
Wt %	24.50	11.70	21.20	5.30	4.30
U_3O_8%	0.25	0.18	0.59	2.37	1.04
Rec %	45.10	11.70	59.00	68.90	61.50
"B" Series: Feed sized, each size 3 passes combined, 25 amp, salient plates.					
	plus 150 mesh				
Wt %	6.30	2.20	7.10	2.20	1.10
U_3O_8%	0.05	0.09	0.38	1.22	0.58
Rec %	3.00	1.00	12.50	14.00	10.90
	150 to 325 mesh				
Wt %	9.00	4.40	8.40	1.90	2.20
U_3O_8 %	0.18	0.14	0.60	3.15	1.01
Rec %	14.70	3.50	23.50	31.20	29.20
	minus 325 mesh				
Wt %	9.70	4.50	8.60	1.70	2.10
U_3O_8 %	0.44	0.23	0.66	2.74	0.97
Rec %	38.50	5.90	26.50	24.30	24.60
	Three above sizes combined.				
Wt %	25.00	11.10	24.10	5.80	5.40
U_3O_8 %	0.25	0.17	0.56	2.30	0.91
Rec %	56.20	10.40	62.50	69.50	64.70

TABLE 33 (continued)

Summary of Magnetic Separations
"C" Series, Ten Consecutive Passes, 25 amperes

AREA	Beaverlodge	Elliot Lake	
MINE	Eldorado	Denison	Nordic
FEED TYPE	Autogenous-mill discharge (-10m)	Class. o'flow*	Ore
Best Condition	Ground ore High-int. plates, Wash	"As received" High-int. plates, Wash	Ground ore (41%-325m) High-int. plates, Wash
	1 Pass		
Weight %	24.20	3.10	4.60
U_3O_8 %	0.44 (0.59)**	1.25 (1.82)**	1.14 (1.72)**
Recovery %	49.60 (46.60)	46.90 (29.90)	67.50 (48.80)
	3 Passes		
Weight %	39.20	6.20	8.00
U_3O_8 %	0.39 (0.53)	0.81 (1.36)	0.76 (1.31)
Recovery %	70.50 (61.20)	60.60 (44.00)	78.60 (62.50)
	10 Passes		
Weight %	52.00	13.90	15.20
U_3O_8 %	0.34 (0.45)	0.42 (0.45)	0.44 (0.65)
Recovery %	81.50 (72.10)	71.40 (56.20)	85.90 (74.60)

*Some uranium lost in solution from long storage as a pulp (Table 14).

**Brackets enclose results from salient-pole plates.

TABLE 34

Summary of Magnetic Separations (Jones), Special Treatment, Denison Mines Limited

TREATMENT "1",	Classifier Overflow, Size and Magnetic Fractionation, Regrind, and Transfer to Next Sizes				
Combined Weight %	16.40				
" U_3O_8 %	0.89				
" Recovery %	79.50				
TREATMENT "2",	Ore Sample, Systematic Reduction in Size, and Magnetic Separation				
Feed Size - Start	-28 m	-28 m	-48 m	-65 m	-100 m
Plates	Salient-Pole	High-Intensity	High-Intensity	High-Intensity	High-Intensity
3 Passes Weight %	3.20	5.80	7.00	6.20	2.70
1 Step U_3O_8 %	1.68	1.21	1.19	1.59	2.60
Recovery %	42.60	58.90	70.50	69.30	58.00
9 Passes Weight %	8.20	8.90	11.80	10.40	7.00
3 Steps U_3O_8 %	1.09	1.03	0.81	1.06	1.34
Recovery %	71.70	77.10	80.60	77.90	77.60
36 Passes Weight %	17.30*	18.00	22.40	27.50	17.40
12 Steps U_3O_8 %	0.60	0.56	0.46	0.45	0.60
Recovery %	82.70	84.80	86.60	87.20	86.30

TREATMENT "3", Classifier Overflow, 25 Amperes, No Wash Water			
No. of Passes	1	3	8
Weight %	25.80	56.00	88.10
U_3O_8 %	0.18	0.11	0.07
Recovery %	65.80	85.30	97.30

*30 passes, 10 steps.

DISCUSSION

The magnetic susceptibilities of the uranium ores varied widely. This resulted in very little, if any, concentration of the Gunnar ore, but in appreciable concentrations of the Eldorado, Denison and Nordic ores. The sample from Faraday responded between the extremes, and Can-Met ore did not respond as well as expected.

In Table 33 the combined results have been broken down into the three series, A, B, and C.

When the programme started, the potential of the Jones separator on fine sizes was just beginning to be realized. It was thought that a grind, fine enough to release mineral particles that would remain on the magnetic plates, would suffice for good recoveries. Therefore, in Series A, representative grinds of all samples were passed through the separator three times at maximum amperage with the expectation that good upgrading would be achieved. Because a commercial process was being sought, salient-pole plates, which gave a larger through-put than high-intensity ones, were used in the separator; also, though in practice a single pass would be most economical, three passes were used to "level out" performances.

This treatment was not promising. Results ranged from no concentration from Gunnar (Table 2) -- the magnetics analysed the same as the feed -- to 68.9% recovery from Denison (Table 12) in a small-weight, high-U_3O_8 fraction.

To establish where the losses occurred, the feed to the Jones separator was screened into plus 150-, 150 to 325-, and minus 325-mesh fractions. Each was treated the same as the unscreened samples (Series B).

Referring to the most promising results, distribution losses in the minus 325-mesh fractions were the largest: e.g., Faraday - 37.5% of a total of 43.8% (Table 10); Eldorado - 31.8% of a total of 37.5% (Table 6); Denison - 21.8% of a total of 30.5% (Table 13); and Nordic - 24.9% of a total of 35.3% (Table 28).

The investigation was narrowed down to the three samples (Eldorado, Denison, and Nordic) that had given the most favourable results. Two approaches were tried. The number of passes through the separator was increased to 10, and this procedure was repeated with high-intensity plates to remove particles of lower magnetic susceptibility (Series C).

Some data shown under this series (Table 33) are not included with the experimental section.

Under the optimum experimental conditions, such as particle size and wash procedures, that were employed, the use of high-intensity plates substantially increased recoveries over those obtained using salient-pole plates: Eldorado from 72.1% (no table) to 81.5% (Table 7); Denison* - from 56.2% (no table) to 71.4% (Table 14); and Nordic - from 74.6% (Table 29) to 85.9% (Table 31).

Samples from the Denison mine, which had shown the most promise at that stage of the programme, were used in a more detailed investigation to try to maximize recovery. Some results of this phase are combined in Table 34 and referred to as Treatments "1", "2" and "3".

Treatment "1" combined a more complicated procedure (Table 15) for treating the screened fraction (4.0.4), with no wash water being used in one of the separations. Recovery increased to 79.5% in 16.4% of the feed weight, grading 0.89% U_3O_8. Interesting features of this recovery were (a) the magnetics in the minus 325-mesh fraction contained 0.69% U_3O_8 in 6.6% of the weight when salient-pole plates were used with no wash water, and (b) additional magnetics were removed with high-intensity plates and wash water from this treated fraction (0.24% U_3O_8 in 3.8% of the weight). In this case, the minus 325-mesh material responded well to magnetic separation.

Treatment "2" was based on keeping fines to a minimum until all possible uranium had been removed. Aliquots of the head sample were reduced dry with a minimum of fines to minus 28 mesh (Tables 16-17), minus 48 mesh (Table 18), minus 65 mesh (Table 19), and minus 100 mesh (Table 20). Each product was subjected to intensive magnetic separation before being ground a little finer, which procedure was repeated for as many as twelve steps. After this drastic treatment, the material being removed was significantly higher in U_3O_8 than that left behind.

Samples of the "step 1" magnetics and the "step 12" non-magnetics from the minus 48-mesh feed (Table 18) were examined mineralogically (2). Polished sections were prepared, from which autoradiographs were made and used to locate radioactive grains, whose compositions were identified by microscopic study and confirmed by X-ray diffraction analysis. The results showed that the main constituents of the first magnetic concentrate were pyrite, goethite, rutile, brannerite-anatase, monazite, and uraninite. There were trace amounts of chalcopyrite. Traces of galena were present in the uraninite. No magnetic minerals, such as magnetite or

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*Data from Denison in Series C should not be compared with A and B, because the sample (classifier overflow) had been kept as a pulp and some uranium was considered to have been lost.

ilmenite, were observed. There was also a small proportion of non-metallic minerals, principally quartz and quartz-sericite. For the most part both metallic and non-metallic minerals were present as free grains.

The grain size of the final magnetic tailings was extremely fine, and no indication of radioactivity was observed in the autoradiographs. This sample consisted of non-metallic minerals and minor amounts of metallic minerals, chiefly pyrite.

Treatment "3" was carried out to check the effect of using no wash water during the operation of the Jones separator. Clean separations were not possible with this procedure because material built up on the plates, resulting in the recovery of a low-grade, bulky, magnetic fraction. This procedure was not outlined under the experimental work.

The results shown in Tables 22 and 24 are for the most recent sample of Denison ore, passed once, twice, and three times, in separate experiments, through the Jones separator equipped with salient-pole plates. Three passes gave a recovery of 53.5% of 2.08% U_3O_8 grade in 3% of the feed with a 15-minute grind, and a recovery of 50.6% of 2.07% U_3O_8 grade in 2.8% of the feed with a 30-minute grind; two passes with the finer grind gave a recovery almost the same as that obtained with three.

Ore from Can-Met Explorations Ltd. concentrated almost entirely in the first magnetic fraction (Table 25). Since it did not behave like the Denison ore, the sample was thought not to be representative; it contained a dark fraction which may have been diabase.

Ore from the other Elliot Lake mine, Nordic, was treated after the detailed work with Denison had been completed. Series "A" and "B" (Table 33) gave similar recoveries and weights to those obtained with Denison. In Series "C", 10 passes of an ore ground for 30 minutes gave a recovery of 74.6% with salient-pole plates (Table 29), and 83.6% with high-intensity plates (Table 30); with a 20-minute grind and high-intensity plates, recovery was 85.9% (Table 31); the coarse, 10-minute grind lowered recovery to 83.8% (Table 32).

In an effort to ascertain whether the magnetic susceptibilities of uranium minerals had ever been measured, a canvass was made of scientists in the Mines Branch and the Geological Survey of Canada. No knowledge of such measurements was revealed, nor was any information derived from literature perused. Earlier experimental work (1), and mineralogical studies associated with the present work (page 32), indicate that brannerite, monazite and uraninite have sufficient susceptibility to be collected magnetically. This is substantiated by the experiments now being reported, the best results being obtained from Elliot Lake conglomerate ores containing brannerite, monazite and uraninite. A lower level of concentration was obtained with pegmatite ores containing uraninite, that from Eldorado in the Beaverlodge area being somewhat better than that from Faraday in the Bancroft area. Eldorado ore also contains pitchblende, while Faraday contains uranothorite. Thus there is a suggestion of an order of decreasing magnetic susceptibility for the uranium minerals, i.e. brannerite, monazite, uraninite, pitchblende, uranothorite. There is also the suggestion that associated minerals play a considerable role in the separation: the presence of diabase in the Can-Met ore masked the effect on uranium minerals; no concentration was obtained with Gunnar ore.

Additional unresolved questions include: why are successive magnetic fractions released by regrinding Denison ore even at extremely fine sizes, and why does a small U_3O_8 content remain in the non-magnetic fraction even after such fine grinding? These and other questions might be answered in a longer programme, which should include the development of accurate data on the magnetic susceptibility of uranium-bearing minerals, and probably the use of super-cooled magnets.

It is recognized that commercial magnetic separation requires a one- or two-pass treatment to be economical. None of the work reported appears to fit such a requirement, although one-pass results with Denison and Rio Algom were highly indicative, and raise the following possibilities:

1. Some plants may be able to recover losses in their tailings if these are present in a magnetic fraction.

2. With new uranium orebodies, magnetic separation has a potential for:

   (a) Decreasing the amount of material to be treated and likely eliminating many acid- consuming constituents; a lower-cost plant might suffice.

   (b) Use in combination with other low-cost treatments such as bacteriological leaching. A small plant treating a high-grade magnetically separated fraction would produce day-to-day revenue while treatment of the remainder of the ore could take place over a longer time.

CONCLUSIONS

1. Although strong magnetic susceptibility among the uranium minerals present in Canadian ores was not detected, the following order of decreasing magnetic susceptibility was inferred:

brannerite--monazite--uraninite--pitchblende--uranothorite.

2. The highest concentrations of U_3O_8 by magnetic means were obtained from Elliot Lake conglomerate ores containing brannerite, monazite and uraninite. With ores from Denison and Nordic Mines, approximately 70% of the U_3O_8 was concentrated in 5 to 7% of the feed weight with one pass through the magnetic separator; however, with these same ores, up to 12 passes succeeded in concentrating only 87% of the U_3O_8 in 27% of the feed weight. With ore from the Can-Met Mine containing diabase, which was sufficiently magnetic to report in the magnetic concentrates with the uranium minerals, 95% of the U_3O_8 was concentrated in 75% of the feed weight with one pass through the magnetic separator; 98.9% of the U_3O_8 concentrated in 84.8% of the feed weight after 6 passes through the separator.

3. Lesser concentrations of U_3O_8 were obtained from pegmatite ores containing uraninite, and there were inconsistencies: a) between ores from different areas (Bancroft and Beaverlodge), and b) between ores with different mineral associations (Faraday, Eldorado and Gunnar mines).

4. With new ore bodies, magnetic separation should be examined as a method of pre-concentration to reduce the bulk of the ore and the amount of acid-consuming constituents. It should also be examined as an adjunct to other low-cost treatments such as bacterial leaching.

5. Solution to questions which could not be resolved within the scope of this project should be sought through a more comprehensive study which should include the development of accurate data on the magnetic susceptibilities of uranium minerals and on the effect of applying the high field strengths obtainable with super-cooled magnets.

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P. Vanasse, P. R. Lachapelle and S. T. Lepage, of the Industrial Minerals Milling Section of the Mineral Processing Division, carried out the experimental work.

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