DRAFT PAPER ON
THE PRODUCTION & MANAGEMENT OF
DRY TAILINGS IN COAL AND URANIUM

by

A. MacG. Robertson, P.Eng. Ph.D.

&

J. W Fisher, P.Eng.
# TABLE OF CONTENTS

<table>
<thead>
<tr>
<th>Section</th>
<th>Page No.</th>
</tr>
</thead>
<tbody>
<tr>
<td>Summary</td>
<td>1</td>
</tr>
<tr>
<td>1. Introduction</td>
<td>1</td>
</tr>
<tr>
<td>2. Methods of Producing 'Dry' Tailings</td>
<td>4</td>
</tr>
<tr>
<td>3. Methods of Handling 'Dry' Tailings</td>
<td>5</td>
</tr>
<tr>
<td>4. Production of 'Dry' Tailings at Coal Mines</td>
<td>11</td>
</tr>
<tr>
<td>4.1 Nature of Coal Wastes</td>
<td>11</td>
</tr>
<tr>
<td>4.2 Development of 'Dry' Tailings Method</td>
<td>11</td>
</tr>
<tr>
<td>4.3 Practical Methods for De-Watering Fine Coal Tailings</td>
<td>13</td>
</tr>
<tr>
<td>4.4 Handling of 'Dry' Coal Tailings</td>
<td>22</td>
</tr>
<tr>
<td>5. Production of 'Dry' Tailings at Uranium Mines</td>
<td>22</td>
</tr>
<tr>
<td>6. Handleability of 'Dry' Uranium Tailings</td>
<td>25</td>
</tr>
<tr>
<td>6.1 U.S. Experience</td>
<td>25</td>
</tr>
<tr>
<td>6.2 South African Experience</td>
<td>28</td>
</tr>
<tr>
<td>6.3 French Experience</td>
<td>28</td>
</tr>
<tr>
<td>6.4 Conditions &amp; Trends in Canada</td>
<td>29</td>
</tr>
<tr>
<td>7. Conclusions</td>
<td>30</td>
</tr>
<tr>
<td>8. References</td>
<td>31</td>
</tr>
</tbody>
</table>
LIST OF FIGURES & TABLES

FIGURES

FIGURE 1: GRADING OF DIFFERENT TAILINGS 6
FIGURE 2: BLOW COUNT VERSUS MOISTURE CONTENT FOR MASSIVE SULPHIDE TAILINGS IN LIQUID LIMIT APPARATUS 8
FIGURE 3: BLOW COUNT VERSUS MOISTURE CONTENT FOR MASSIVE SULPHIDE TAILINGS WITHOUT AND WITH 5% BENTONITE ADDED 10
FIGURE 4: TYPICAL BELT PRESS (Andritz) 15
FIGURE 5: TYPICAL BELT PRESS FILTRATION CYCLES (Parkson) 16
FIGURE 6: MULTI BEND BELT FILTER 17
FIGURE 7: MULTI BEND BELT FILTER 18
FIGURE 8: DIAGRAM SHOWING FILTRATION PRINCIPLE (Edwards & Jones Inc.) 19
FIGURE 9: FILTER PRESS PLANT - AS USED ON A TYPICAL URANIUM PROCESS WASTE PRODUCTS (Willet Pumps & Edwards & Jones Presses) 20
FIGURE 10: TYPICAL URANIUM PROCESS WASTE PRODUCTS 22
FIGURE 11: TYPICAL 1000 TPD MILL WITH CCD & WET TAILINGS 23
FIGURE 12: 1000 TPD MILL WITH CCD & TAILINGS Dewatering 24
FIGURE 13: 1000 TPD MILL WITH TWO BELT FilTRATION UNITS IN SERIES - (For Uranium Recovery & Tailings Dewatering) 26
FIGURE 14: SOME TYPICAL URANIUM TAILINGS GRADING CURVES 27

TABLES

TABLE I: WATER & TAILINGS DATA FOR TYPICAL OPEN & CLOSED CIRCUITS 12
TABLE II: SUMMARY COMPARISON OF CAPITAL & OPERATING COSTS FOR BELT & FILTER PRESSES FOR COAL REFUSE Dewatering 21
TABLE III: ESTIMATE OF COSTS FOR BELT filtration (1000 Tonnes/Day) 25
Public and industry concern at the increased quantities of mine waste, a few catastrophic failures and the short and long-term pollution potential of mine wastes have increased the need for new and better techniques for mine waste disposal. The production and management of dry tailings present some considerable advantages in this regard. Rapidly developing technology and reliable equipment for the production of dry tailings are making it viable in an increasingly large number of operations. Techniques for the production and handling of dry tailings are reviewed.

Coal has been in the forefront of this area of technical development as the increased value of product recovery after beneficiation has compensated for the additional costs of processing and waste management technology necessary to comply with higher regulatory standards. Uranium, because of its products value as well as the intrinsic pollution potential of its tailings, is on the verge of similar developments. This paper reviews existing and potential application of dry tailings technology to the treatment and management of wastes from coal and uranium operations.

1. INTRODUCTION

Tailings and other mining or milling waste products are being produced in ever increasing quantities, in disproportionate rates to the rate at which the products themselves are being produced. The accelerated production rate is largely due to the mechanized mining of poorer coal seams or continually decreasing ore grades, at higher stripping ratios and in larger scale operations. Old waste piles or tailings impoundments, unlike the products, don't go away, get consumed, or have a useful purpose. They accumulate and consume land space in competition with other uses and may become the source for air, surface or groundwater pollution. In isolated, but tragic cases, they have proved to be unstable and catastrophic failure has resulted in substantial losses of life and property.

* President, Steffen Robertson & Kirsten (B.C.) Inc.
** Associate Consultant, Steffen Robertson & Kirsten (B.C.) Inc.
Large failures with substantial losses in life have received wide publicity and have served to focus the attention of industry, government and the public on the potential concerns associated with these waste deposits. No product is exempt. Failures where the numbers killed are numbered in tens or more include Buffalo Creek and Aberfan (in coal), El Cobre (in copper) and Bafokeng (in Platinum). Many other large failures have occurred, fortunately most without loss of life, and are still occurring, as evidenced by the recent Church Rock (uranium) and Tyrone (copper) failures in the United States. Of significance to these latter impoundments is that they were designed and constructed by specialists in the field to nearly present standards.

It is argued that these represent a few isolated cases in the very long history of successful waste management, and that technology and both regulatory and industry controls are continually improving to reduce the potential for future failures. It is also noted that because of the scale of the projects now being initiated, the tailings and waste dump designer is required to produce designs for impoundments of ever increasing size and rates of rise, and is therefore continually stepping beyond the bounds of previous experience. Our technology is scale and time rate dependent and the extrapolation of such technology, particularly in the variable field of mine wastes, must always be attended by some risk. All the failures named, and nearly all that occur, result from water flowing through, or the generation of pore water pressures in, the waste.

In addition to the risk of failure of an impoundment or waste pile there is a risk of pollution. While air, surface and groundwater pollution must all be controlled, it is the short and long-term protection of surface and groundwater quality that is generally the most difficult. Seepage and leaching from the wastes, both during operation and following closure, if not adequately catered for, can have a long-term detrimental impact on the environment. The mobility, importance and increasing scarcity of water makes this the single most important environmental issue at most mining projects.

The drainage and control of water associated with tailings impoundments and waste dumps is therefore critical to both the stability and pollution potential. Current designs for tailings disposal facilities give careful attention to such drainage and water control measures and many different approaches can be used. They can be broadly classified into two groups:

(i) those that prevent seepage by the installation of a barrier or liner: impoundments of this type generally contain the tailings, in a saturated state, in a 'basin' formed by natural or man-made embankments: and

(ii) those that allow or induce seepage by using permeable embankments or underdrains: pollution may be controlled by liners under the drains and by collecting seepage for return or processing.
A third group was previously only generally applicable to mine waste or other materials which had associated with them a sufficiently low moisture content that they could be placed as a granular 'dump' from which very little free water would drain. This group is now also finding increasing application in the field of tailings. Briefly they may be described as:

(iii) those that 'dry' the tailings in the plant to a degree sufficient to be able to handle the product by conventional 'dry' materials handling equipment: such a waste may be placed in the field in a waste dump with little free water available for seepage.

This latter group of solutions is finding increasing application largely for the following reasons:

(a) Minimizes the volume of contaminated solutions available for pollution release.
(b) Maximizes recycle solution to the mill and minimizes reagent consumption and make up water needs.
(c) Reduces the potential for pore pressure development and waste embankment failure or flow
(d) Permits greater freedom in the location of the waste disposal site, valleys can be avoided if necessary.
(e) Improves ease of reclamation, minimizes size of unreclaimed area exposed at any time and permits reclamation to be completed immediately when milling ceases.
(f) Minimizes the potential for long-term pollution or instability.

Two further reasons are becoming increasingly significant in the adoption of 'dry' tailings solutions:

(g) The tendency to produce a finer tailings product to liberate the desired product. This applies to the wash products in coal where the increased coal prices have made it economic to wash down to very fine sizes and to the increasingly fine grind being applied to metal ores such as molybdenum, gold and massive sulphides. Drainage time is proportional to the square of the particle diameter. Thus, very slow drainage occurs in the field from such fine tailings. Further, with substantial portions of these fine tailings composed of micron-sized particles, often clay particles, low densities are experienced in the field. This increases the tailings volume, water available for pollution release and problems of reclamation.
(h) In recent years there have been rapid strides made in the development of techniques and large equipment suited to the de-watering of tailings products. Thus, the economics of liquid-solid separation for these fine wastes have improved rapidly.
In reviewing the overall economics of a dry tailings disposal alternative it is important that all economic factors be considered. Often overlooked are the 'defensive costs'. These are expenses necessary to comply with new rules and regulations, which may be promulgated during the life of the operation and to address public concerns and pressures. In the long term these 'defensive costs' can have a significant effect on the overall economics of the venture.

2. METHODS OF PRODUCING DRY TAILINGS

Tailings consist principally of ground-up rock, with a variable size distribution, mixed with water to different pulp densities. The water may contain many dissolved chemical constituents of varying concentrations. It is a potential pollutant. The ease with which the tailings de-waters will depend largely on the following three factors:

(i) the average particle size of the tailings,
(ii) the percentage of very fine material (minus 2μ), and
(iii) the nature of the clay-sized particles (montmorillonite, illite or kaolinite).

De-watering ease will generally increase with increase in average particle size, decrease in percentage of very fine material and with lower clay contents, particularly montmorillonite.

Much can be done to improve the de-watering capability of the tailings by conditioning with flocculants. The relationship between these factors and de-watering is not straight forward and is the subject of considerable investigation at a number of centres at this stage, CSMRI (1981), Yancey and Geer, Frankfort (1978), and von Michaelus (1979).

De-watering methods for tailings can be ranked in approximate order of decreasing ease with which the water is removed.

(i) Gravity drainage - can be applied to freely draining tailings generally where the material has a D_50 particle size greater than 0.2mm and less than 10% finer than 0.075mm (silt sized).
(ii) Cycloning plus gravity drainage - can be applied to de-water the coarser fraction of tailings. Fine tailings in the overflow must be treated by one of the methods below
(iii) Centrifuge de-watering - can be used to partially de-water almost the total tailings product. Very fine tailings in the effluent must be treated separately and coarser solids are still 'sloppy'.
(iv) Vacuum filtration using disk, drum or belt filters - can be used to create high hydraulic gradients over thin layers of cake to improve de-watering efficiency. Their effectiveness is limited by cake cracking and suction limitations.
Pressure filtration using either belt or filter presses produce increased hydraulic gradients through thin cakes and this can be used to de-water the finest of tailings. Positive controls that can be applied in pressure filters makes them an effective and flexible de-watering device.

Illustrated in Figure 1 are the gradings for five different tailings products. Tailings A is the cycloned sand (underflow) from a copper tailings. This sand is sufficiently coarse to be relatively free-draining. It can be placed in the field at its discharge moisture content and, with adequate under-drainage, will behave as a granular waste and be stable in a pile which has 3:1 side slope.

Tailings B is a little finer for the coarser 50% of its grading curve but contains a much higher percentage of clay fines, indicated by the high tail. These tailings are being belt filtered to approximately 35% moisture content and are 'sloppy' when handled by earth moving equipment.

Tailings C, despite being considerably finer than tailings B, on average, has a much lower clay content. Because of its lower clay content it can be economically belt filtered down to 18.5% moisture content. The product has a high specific gravity and at this moisture content is still fairly 'sloppy' to be handled by earth moving equipment.

Fine coal wastes D and E are both relatively fine and have high clay contents. Test results, CSMRI (1981), on these show that waste D can be effectively and economically de-watered using either a belt press or a filter press while either a centrifuge or a drum vacuum filter would not be suitable. Unlike waste D, waste E contained a substantial amount of montmorillonite and was extremely difficult to de-water by any method.

An initial assessment of tailings de-watering ability can be made based on the above three factors and comparisons with similar tailings elsewhere. The authors are currently compiling an index of such information. Leaf filter tests, (Purchas, 1972) or variations thereof, (Moir and Read, 1975), may be used to make comparative studies to determine conditioning potential benefits and costs and to confirm general de-watering characteristics of the tailings slurry. Final selection of equipment and process method must be done on pilot scale equipment from which final scale up data can be developed. Such testing apparatus or services can generally be arranged with the equipment supplier or suppliers selected.

3. METHODS OF HANDLING DRY TAILINGS

De-watered tailings are not dry, but possess a residual moisture content which typically varies from 8% to 40% of total weight. At these moisture contents they vary in consistency from a thick slurry to a granular material or a cohesive cake with little free water. The handleability of these products varies tremendously.
TAILINGS A — CYCLONE UNDERFLOW FROM A COPPER TAILINGS
TAILINGS B — TOTAL TAILINGS FROM A URANIUM ORE
TAILINGS C — TOTAL TAILINGS FROM MASSIVE SULPHIDE ORE
For the purposes of this paper, tailings are considered to be 'dry' if they have been de-watered sufficiently that they can stand in a substantial pile and be handled by conventional earth moving equipment without liquifying (or slopping about). Non-cohesive tailings would generally attain this state at relatively low moisture contents of 10% to 20%. Cohesive tailings could have moisture contents in excess of 35% and still be considered 'dry'.

As the moisture content of the tailings increases it tends to become more sloppy. At moisture contents a little above the 'dry' level, it may stand in a slumped pile but it would tend to flow and slop about as soon as it is disturbed or vibrated. This change in properties, on disturbance, is due to a reduction in shear strength brought about by an increase in the pore water pressures developed in the tailings. At yet higher moisture contents the tailings become a slurry with viscosity dependent on the percentage of solids contained.

Our interest in the handleability of the tailings by conventional earth moving equipment is effectively in the range where it behaves as a solid waste through to a sloppy product. Sloppy tailings products can, and are, being loaded from settling lagoons, sludge ponds, etc., by front end loaders and hauled by truck for co-disposal with rock waste. The sloppier the product the more inefficient is the loading and transportation. Tailings both slop from the buckets and truck backs and pour out of tail-gates. A large amount of energy is expended loading and hauling water rather than solid product. Spillage on haul roads causes a mess and increases the maintenance costs. Since the sloppy tailings will not support the loading and transporting equipment, a 'firm bottom' is needed. At the discharge location containment is required if the product tends to flow and trafficability over the disposed product becomes a problem.

Concerns relating to the handling of the tailings can be grouped in three major areas:

(i) Handleability: refers to the methods by which it can be loaded and transported and placed.
(ii) Trafficability: refers to the problems that will be encountered by equipment moving on it during loading or following placement in the disposal area.
(iii) Stability: refers to the stability of the product when placed in the field and therefore the geometry to which it can be placed or the containment that it may need.

A convenient measure of the sloppiness of a tailings product can be made using the Atterberg Liquid Limit Apparatus, Lambe (1967). A few cubic centimeters of the tailings product are placed in a bowl in this apparatus and a groove of standard width is cut in it. The bowl is then jarred with a standard energy (blows) a repeated number of times until the tailings flow to close the groove. A plot of the number of blows required against the moisture content of the tailings is made and is illustrated in Figure 2.
FIG. 2  BLOW COUNT VERSUS MOISTURE CONTENT FOR MASSIVE SULPHIDE TAILINGS IN LIQUID LIMIT APPARATUS
The moisture content defined by this curve at 25 blows is called the Liquid Limit, a property commonly used in soil mechanics. A liquid limit of 12% applies to the example illustrated. It should be noted that in this curve, the soil mechanics convention, in which the moisture content is taken as a percentage of the dry weight of tailings, is used.

Tailings at moisture contents above the liquid limit have a low shear strength which decreases with increasing moisture content as illustrated by small amounts of energy needed to get the groove to close. At moisture contents a little below the liquid limit there is a rapid increase in the shear strength and resistance to flow. Tailings with moisture contents below or a little above the liquid limit can generally be handled by conventional earth moving equipment. Trafficability usually requires moisture contents appreciably below the liquid limit, as does stability if containment is not provided.

Additional tests can be performed on dryer filter cake products and these will provide more direct measures of the tailings characteristics which are of interest to trafficability and stability factors. These include penetrometer testing, torque vane, trafficability cone and shear testing.

Only limited information is available on the trafficability of mine wastes and tailings products, [Nowatski (1981 and 82)]. The authors are currently involved in a study to evaluate trafficability of selected tailings products at different moisture contents.

From the results of an investigation into the de-waterability of the tailings under construction, the moisture content of the end product can be estimated. Using the above methods of testing an evaluation can be made of the handleability, trafficability, and stability, and a waste disposal management system can be designed. This may involve truck, conveyor or aerial tramway transport and a number of alternative loading and placing techniques. Field placement may be possible in conjunction with other wastes and may require containment dykes. Co-disposal with other mine wastes offers a number of options which can be used to improve trafficability at the dump site, improve stability and provide containment. To achieve this, waste may be either intermixed, interlayered, or used to construct berms.

Detailed descriptions of these field options are beyond the scope of this paper.

Figure 3 illustrates the change in the liquid limit curve brought about by the addition of 5% bentonite. This relatively small addition has increased the liquid limit from about 12% to about 19% with a commensurate increase in the handleability of the tailings. Other additives being investigated include lime, cement and finely crushed rock waste. The economics of tailings improvement by admixtures compared with additional de-watering are currently being evaluated but will be site specific and depend on the degree of improvement required, the availability and cost of admixtures, and ease with which the tailings can be further de-watered.
FIG. 3  BLOW COUNT VERSUS MOISTURE CONTENT FOR MASSIVE SULPHIDE TAILINGS WITHOUT AND WITH 5% BENTONITE ADDED
Following placement in the field additional reductions of moisture content in the tailings can be obtained by underdrainage and air drying. Design and management techniques to maximize these are beyond the scope of this paper but aspects are considered in earlier papers by Robertson and Van Zyl (1980).

4. PRODUCTION OF DRY TAILINGS AT COAL MINES

4.1 Nature of Coal Wastes

Coal mine wastes are generally a variety of sedimentary rock types some of which may have a potential to produce acid. They are disposed of in dumps or tips as a 'dry' product.

Wet wastes originate from coal preparation facilities and can be broadly classified into coarse and fine waste. Coarse wet refuse ranges in size down to 1mm with fine wet refuse ranging from 1mm to clay size particles. The clay content of the fine refuse may be variable both in type and amount. Fine refuse is usually thickened (in a thickener) to between 15% and 35% solids prior to disposal in settling ponds. It may contain substantial quantities of amorphous coal, quartz, feldspar and clays. Dolomite and calcite may also be present.

4.2 Development of 'Dry Tailings' Method

The conventional system of using settling ponds is workable particularly when the fine refuse contains appreciable quantities of granular coal which helps ponds to drain at a reasonable rate. More recently the lower rank thermal coals supplied to electrical utilities had to be improved considerably in quality as a result of the introduction of tighter environmental specifications for power station operators and the realization by buyers that there are overall benefits to be gained from using higher quality fuels. Better quality fuel commands a higher price and many thermal coals as well as metallurgical coals are now washed products.

It has also become more attractive to wash the finer sizes of r.o.m coal to produce a higher yield of salable product. In doing this the fine coal refuse remaining has a higher ash content and is usually less granular. It is, therefore, a more difficult material to 'dry out' when left in settling ponds and this is a major factor to be considered in the design stages of new coal preparation facilities.

In a typical medium sized coal preparation plant with a capacity to treat 500 tons r.o.m coal/hour probably 30% of the feed will be less than 0.5mm in size. The proportion of fine refuse may be 10% to 15% of r.o.m. feed. This represents 50-75 tons fine refuse/hour. Most plants operate continuously. Thus, one day's operation will produce 1000 to 1500 tonnes fine refuse in a relatively low solids content pulp.
At 1.2 SG and 20% solids, 1000 tonnes fine refuse is contained in a bulk of approximately 4400m³ (155000 ft³) which must be disposed of within a tailings impoundment if no further process treatments are to be used. Some further settlement of solids will occur but this is at a very slow rate and only small quantities of water are recoverable. Thus, the tailings impoundment remains fluid for a long time after the final addition of slurry. Some recent experiences in the US (Bradbury 1980), have shown that lower than anticipated settled densities mean that impoundments fill very much more rapidly than expected. Considerable difficulties can result in maintaining production while preparing and permitting new disposal areas or cleaning out the low density sloppy settled products from existing facilities. De-watered 'dry' coal refuse is usually a simple mine waste product to dispose of and with many shallow open pit operations it can be backfilled into worked out areas and finally covered to yield a usable land form within a short period of time.

Unlike some tailings slurries the water contained in fine coal slurries can be recycled for further use when the solids have been removed. The concept of a 'closed water circuit' or 'zero water discharge' from a coal washery is a relatively simple idea compared to other more complex process operations. De-watering of the fine refuse in the plant permits the adoption of a 'closed water circuit' with all the attendant advantages relating to water consumption and environmental protection. Table 1 serves to illustrate some comparative water balance data for a typical coal washing plant using settling ponds or a 'dry' refuse disposal system.

### TABLE 1: WATER & TAILINGS DATA FOR TYPICAL OPEN & CLOSED CIRCUITS

<table>
<thead>
<tr>
<th>BASIS = 10000 R.O.M (Coal)</th>
<th>[OPEN CIRCUIT SYSTEM] (Settling Ponds)</th>
<th>[CLOSED CIRCUIT SYSTEM] (Dry Refuse Disposal)</th>
</tr>
</thead>
<tbody>
<tr>
<td>Make Up Water (US GPM)</td>
<td>850</td>
<td>240</td>
</tr>
<tr>
<td>Vol. Coarse Refuse (m³/Day)</td>
<td>850 - 900</td>
<td>850 - 900</td>
</tr>
<tr>
<td>Vol. Fine Refuse (m³/Day)</td>
<td>3400 - 3600</td>
<td>800 - 850</td>
</tr>
<tr>
<td>Est. Final Vol. Coarse Tails (m³)</td>
<td>$5 \times 10^6$</td>
<td>(combined) $10 \times 10^6$</td>
</tr>
<tr>
<td>Fine Tails (m³)</td>
<td>$12 \times 10^6$</td>
<td></td>
</tr>
<tr>
<td>Total (m³)</td>
<td>$17 \times 10^6$</td>
<td></td>
</tr>
<tr>
<td>Monitoring &amp; Control of Effluents</td>
<td>Required During &amp; After Oper.</td>
<td>Not Required</td>
</tr>
</tbody>
</table>

Table 1: Based on plant treating 500 tons r.o.m feed/hour.
Yield = 80%
Coarse refuse = 10% (-25 + 0.5mm)
Fine refuse = 10% (minus 0.5mm)
Daily operation 20 hours 300 days/year 20-year life.
Because of these advantages numerous dry systems have been installed in Europe and are now being used increasingly in the eastern United States.

4.3 Practical Methods for De-Watering Fine Coal Tailings

Almost all fine refuse de-watering methods employed are filtration systems. One or two installations in U.S.A. use centrifuges but these are exceptions. Pressure filtration techniques have become more versatile and sophisticated than they were five to ten years ago and coal refuse de-watering is done by either batch (filter presses) or continuous (belt presses) equipment. The choice of method depends essentially on the quantities and characteristics of the refuse material.

Continuous Pressure Filter (Belt Press)

Several companies manufacture belt presses for use on coal fines, coal refuse and other suitable filtration applications (Green 1981). The principle of operation is based on a filtration cycle which includes natural drainage of water from the slurry followed by one or more stages of pressure filtration which occur when the cake solids are squeezed between two belts. Operation is continuous and belt speeds, as well as applied pressure, can be varied considerably. Figure 4 is a typical belt press (Andritz). Advantages claimed for this type of mechanical filtration are:

- low power consumption,
- high solids content of cakes, and
- continuous operation.

Fine coal refuse, first thickened to a pulp containing 15 - 35% solids, is mixed with moderate quantities of a polyelectrolyte type flocculant and this mixture is introduced onto a continuous moving open mesh belt. Considerable water is removed by gravity drainage through the belt. As the partially de-watered solids move along the belt they are gradually confined and squeezed by the upper belt which forms the boundary at which pressure is applied by means of rollers. Total filtration time is 4 to 6 minutes. At the end of the cycle filter cake is discharged and the filter belts are backwashed.

The important technical variables of belt press operation are:

- time for which pressure is applied,
- manner by which pressure is achieved, and
- correct use of right type of flocculant.

Flocculant consumption is moderate to high.
Fig. 4 TYPICAL BELT PRESS (Andritz)
Fig. 5  TYPICAL BELT PRESS FILTRATION CYCLES (Parkson)
Belt Filter Presses III

(MULTI BEND)

Contact pressure limited by belt tension
Contact pressure does not increase

- Ashbrook Simon-Hartley "Winklepress"
- Carter
- Komline Sanderson 2-Stage
- Tait-Andritz S Module

Two Stages: Gravity drainage & pressure filtration

Fig. 6 MULTI BEND BELT FILTER
Belt Filter Presses IV
MAGNUM PRESS

Three Stages of Operation: 1. gravity drainage
2. low pressure filtration, and
3. high pressure filtration

Contact pressure increases
Long contact time
Contact pressure not limited by belt tension

Fig. 7   MULTI BEND BELT FILTER
(PARKSON BELT PRESSES)
In the preparation and introduction of feed slurry the effectiveness of flocculation determines the amount of drainage of free water and, to a significant extent, in the pressure stages the subsequent filtration also is affected. Cake bending and shearing during the pressure stages is important because it releases water which otherwise would remain trapped within layers of the solids.

One of the best documented examples of belt filter press application is described by Lynberg (1981) for the Centralia mine in the State of Washington where a 3.5m belt press is being successfully used to de-water a fine refuse with a high montmorillonite clay content.

Batch Filter Press (Recessed Chamber Press)

Filter presses have been used for a long time. However, only during the past ten to twelve years have they been developed into the large high pressure, fully automated units which are to be found at coal washeries in Europe and the U.S.A. The major problems with the older units were the low through-put rates and the high labour requirements associated with manual operation.

The original use of filter presses for de-watering fine coal refuse goes back to the mid-1950's when some coal washeries in the U.K. were producing large quantities of fine refuse which was a difficult problem to handle effectively and safely. In this instance the coal industry learned from the pottery industry, which had used filter presses for some time, to de-water clay slurries. With this technology 'closed circuit' operation of coal washeries was made possible. This has been developed slowly over the years with most of the progress being made in the last ten years.

The large modern filter presses used to de-water fine coal refuse operate at pressures up to 16.5Kp/cm (230 psig) and are fully automated. The time for a complete cycle of operation varies from 30 minutes to about 90 minutes and this is very dependent on the nature of the material to be filtered.

Figure 8 shows the filtration principle for a recessed chamber type filter press.

Typical sizes of these presses are:

(i) 50 - 150 chambers per press,
(ii) rectangular chamber sizes 1m x 1m to 2m x 2m,
(iii) cake thicknesses 25mm to 40mm, and
(iv) actual cake volume about 80-85% of total volume calculated from i, ii and iii above.
RECESSED CHAMBER TYPE FILTER PRESS

**Fig. 8** DIAGRAM SHOWING FILTRATION PRINCIPLE
(EDWARDS AND JONES INC.)
Fig. 9  FILTER PRESS PLANT - AS USED ON A TYPICAL DEWATERING APPLICATION  
(WILLET PUMPS & EDWARDS AND JONES PRESSES)
Figure 9 shows a typical filter press installation with a centrifugal pump for fast filling (unfloculated pulps) and a ram pump for high pressure operation. When the press is loaded and filtration is complete, the excess slurry is drained. The pressure is released allowing the press to be opened and the cake to drop out. Fairly high ash coal refuse (55%-65% ash) containing small amounts of clay minerals can be processed to a final moisture content of 25%-30% after 25-30 minutes filtration time. Approximately 15 minutes is required to drain excess pulp, discharge the cake and re-seal the chambers for the start of the next cycle. Bradbury (1980) provides a description of the selection and implementation of a filter press system for fine coal refuse de-watering at the Martin County Coal Corporations plant on Wolf Creek, Kentucky.

Comparison of Costs (Filter Presses & Belt Presses)

The data in Table II was compiled by the authors from manufacturer's price lists and operating plant experience (USA 1981). The estimation of operating costs for a 5000 tonnes/day installation is an extrapolation of the 2000 tonnes/day installation, based on addition data obtainable from manufacturers and literature. The figures are representative of a particular set of assumed circumstances and are similar in amount to industry experienced figures as quoted by Bradbury (1980) and Lynberg (1981). Rates will be project and material specific and will increase as the de-water ability of the fine refuse decreases. For very fine, high montmorillonite clay content refuse, belt presses appear to have an economic advantage over filter presses. This is borne out by the study reported by Lynberg (1981) as well as CSMRI (1981). This is probably attributable to the fact that additional pre-treatment with flocculants can be used to advantage, and the shearing action in a belt press can be varied. A filter press has less flexibility of operation.

<table>
<thead>
<tr>
<th>TABLE II: SUMMARY COMPARISON OF CAPITAL AND OPERATING COSTS FOR BELT &amp; FILTER PRESSES FOR COAL REFUSE DE-WATERING</th>
</tr>
</thead>
<tbody>
<tr>
<td><strong>ESTIMATE OF COSTS</strong></td>
</tr>
<tr>
<td></td>
</tr>
<tr>
<td><strong>CAPITAL COSTS ($)</strong></td>
</tr>
<tr>
<td><strong>OPERATING COSTS ($)</strong> (PER DAY)</td>
</tr>
<tr>
<td><strong>OPERATING (3) COSTS/TONNE</strong></td>
</tr>
</tbody>
</table>

(1) Availability factor = 0.85  (2) Dry tonnes/day of fine refuse  (3) Includes labor, power, maintenance, spares and reagents (Depreciation excluded)
4.4 Handling of 'Dry' Coal Tailings

De-watered fine refuse from pressure filters and belt presses range in moisture content from about 22% to 50% depending substantially on clay content. The products are well suited for either conveying or truck haulage. Systems have been implemented for waste disposal which use trucks, conveyor and aerial tramway conveyance.

Co-mingling with coarse waste is usually practiced and in this form solid wastes are handled with little or no problems with trafficability or stability. Some separate disposal of wastes is still carried out and in many cases problems with trafficability occur during periods of wet weather.

Dry disposal costs are readily determinable since the major cost component is the transportation and placement. This cost is largely dependent on the length of haulage and is therefore, highly site specific. Total handling and disposal costs reported by Bradbury (1980) amount to about $1.20 per tonne for their project.

Placement and reclamation methods are essentially similar to those for mine waste and the cost of site preparation, pollution prevention, monitoring and reclamation are therefore, considerably less than for wet deposits in settling ponds.

5. PRODUCT OF 'DRY' TAILINGS AT URANIUM MINES

Tailings from uranium plants are much more complex than coal refuse. Physically they may have clay and sands and generally they are fine (usually less than 0.5mm in the upper size limit). For simplicity this section will consider tailings originating from an acid leach circuit. Chemically these solid wastes contain some acid solution in which a variety of elements may exist. Heavy metals, radionuclides and potentially hazardous non-metals such as arsenic and selenium may be present, both in the solution and solids portion of the tailings wastes. There is a limit to how much waste solution can be recycled for re-use in the hydrometallurgical processes.

Figure 10 shows a typical waste product diagram for a uranium mill.
Conventional technology has been to use C.C.D. systems or vacuum filtration for the liquid-solid separation stages on uranium tailings. In these separation stages the first problem is to recover the uranium. Several stages of C.C.D. are necessary to do this (5 to 8 stages usually). When filtration is used instead of C.C.D. less stages are required because each stage of filtration includes cake washing and the removal of uranium is more complete at each stage. Thus, in the uranium recovery process, filter presses or belt presses which apply pressure during the filtration cycle are not really suitable liquid-solid separation devices because cake washing cannot be done. Vacuum filtration is therefore, the preferred de-watering method within the Process.

Filter cake from the drum or belt filters usually contains less water than the C.C.D. product but, very often, this filter cake is reslurried with water so that it can be pumped to an impoundment area. With the use of horizontal belt filters, now accepted as a means of filtration and washing of uranium leach solids, there are interesting possibilities available which may be able to offer distinct advantages in the overall schemes of waste management. In this respect 'dry tailings' appear to be very attractive and this can probably be achieved using less water within the circuit resulting in smaller amounts of waste water for treatment and disposal.

A typical water balance for a mill treating 1000 tonnes ore/day with C.C.D. and wet tailings product is shown in the next figure. The illustrated values are suited to typical Canadian conditions.

**FIGURE 11:  TYPICAL 1000 T.P.D. MILL WITH C.C.D. & WET TAILINGS**

\[
\frac{\text{Water}}{\text{Ore}} = \frac{3666}{1000}
\]

All data are tonnes/day. Approximately 3.7 tonnes water are required per tonne of ore feed.

The tailings area is a substantial open structure constructed to impound water and any net precipitation must be treated. Waste water from tailings dams at Canadian uranium mines cannot normally be recycled because the solution is saturated with gypsum from the neutralization process which is required before tailings are placed in the impoundment areas. Saturated gypsum solutions create problems in the solvent extraction stages of the purification circuit.
The production of 'dry tailings' may be achieved in several ways and Figure 12 is almost the same as Figure 11 but shows the wet tailings filtered to produce a 'dry' cake.

If water from the tailings is recycled to the process the overall water requirements are reduced by 15 to 20% and approximately 3 tonnes of water per tonne of ore feed are required in the process. Further economy of water use may be possible through the use of treated wastewater instead of freshwater for the major process stages. The catchment area for the 'dry' tailings impoundment is significantly less than for a wet tailings area. Consequently there is much less contaminated runoff produced from snow and rainfall.
Tailings de-watering will be an additional operation at the end of the regular process. Lower moisture in the 'dry tailings' and re-circulation of the filtrate to the grinding section will lower the soluble loss of uranium. Negligible seepage is expected from the 'dry tailings' and there is less process waste water to be treated for impurity removal prior to disposal.

It is possible to modify the process to include the use of belt filters in place of the C.C.D. or drum vacuum filter system. Figure 13 shows a possible arrangement for this with an additional stage of belt filtration to increase uranium recovery and to de-water the final tailings product.

**FIGURE 13:** 1000 T.P. DAY MILL WITH T.W.D. BELT FILTRATION UNITS IN SERIES
-(FOR URANIUM RECOVERY & TAILINGS DE-WATERING)

![Diagram of uranium recovery and tailings de-watering process]

This is a generous water allowance for a belt filtration system and it may be possible to operate with considerably less water. Again, it should be possible to attain very low soluble losses of uranium with this system and the waste treatment system is smaller than before.

Some uranium leach solids are difficult to de-water to yield a handleable cake and further measures may be necessary such as the addition of small quantities of dry solids to reduce the overall moisture by 2-4% in order to produce a handleable cake. An alternative possibility might be to use a belt press for the final stage of de-watering shown in Figure 13.

The purpose is to show that there are ways of producing dry tailings and that in the course of investigations it may be possible to make some economic improvement to the plant and waste management sections while extending the state of the art and complying with the tighter environmental controls.
For the schemes outlined in Figures 12 and 13, an estimate of capital costs for belt filtration has been made from budget cost data received from Envirosure N. T. Filtration rate was assumed to be below (approximately 200 - 250 kg/m²/hour). For this duty three units each, with 60m² filter area would be necessary. For each unit, there is approximately 200 installed HP. Labour is low and maintenance costs are moderate (40 - 50c/tonne).

TABLE III: ESTIMATE* OF COSTS FOR BELT FILTRATION (1000 TONNES/DAY)

<table>
<thead>
<tr>
<th>APPLICATION</th>
<th>TAILINGS DE-WATERING (Figure 12)</th>
<th>a) Uranium Recovery &amp; b) Tailings De-Watering Fig. 13</th>
</tr>
</thead>
<tbody>
<tr>
<td>CAPITAL COSTS ($)</td>
<td>$3,000,000</td>
<td>$6,000,000</td>
</tr>
<tr>
<td>OPERATING COSTS**/TONNE SOLID DS</td>
<td>$2.10</td>
<td>$4.20</td>
</tr>
</tbody>
</table>

* Based on data received from Envirosure Inc. NJ
** Includes labour, power, maintenance, supplies and reagents

Costs shown in Table III are based on budget estimates and incremental costs for belt filtration would be expected to be somewhat lower. In a paper presented by Murray, 1979, incremental capital and operating costs for an 1800 tonne/day uranium mill in western U.S.A. have been estimated to be $6.76 x 10 and $1.50 respectively, (1981 dollars). Operating costs for Vaal Reefs on larger belt filters (70 m²) were approximately $1,70 per tonne in 1980 (Robertson 1981 - personal communication with Vaal Reefs) and these have been reduced in the past year to approximately 67c/tonne.

6. HANDLEABILITY OF 'DRY' URANIUM TAILINGS

Considerably less experience exists regarding the de-watering of uranium tailings and their subsequent handleability than does for the coal industry.

6.1 U.S. Experience

The results of amenability tests on some 16 US ores to belt-filtration (Frankfort 1978) indicates that these can be de-watered down to 18% to 23% moisture content. No installations to produce dry tailings have been effected and the handleability of these tailings has not been tried.

A test series with which one of the authors was associated on Wyoming sandstone ore yielded an estimated moisture content of 24%. The grading of the ore was predominantly sand-sized particles with up to 15% clay. A typical grading curve is shown on Figure 14. At this moisture content, the tailings behaved essentially as a granular non-cohesive material and would stand in a pile without slumping. No material difficulties were anticipated in the handling of the tailings or with its placement, though special handling procedures were developed for its placement in the field to cater for potential pollution aspects. Some precautions were required for winter placement.
SOME TYPICAL URANIUM TAILINGS GRADING CURVES

CLIENT
PROJECT
SAMPLE
SOURCE
HOLE
DEPTH
DATE REC'D
LAB
DATE TESTED

PREPARED BY

STEFFEN ROBERTSON & KIRSTEN

REF NO.  FIG. NO. 14
6.2 South African Experience

Uranium tailings are being effectively dried on belt filters to between 15 and 21% moisture content at various installations in South Africa. Dry tailings disposal is not being practiced (for economic and local reasons) and these tailings are being reslurried for wet disposal. Since the achievement of a 'dry' product is not the aim of their de-watering system it is not a good test for the potential de-water ability of their tailings. Some of the more effective installations (Vaal Reef's, for example), are producing a cake which, prior to adding water, appears suitable for dry tailings disposal without significant handling problems. Co-mingling with rock waste or management to allow field drying may be required to improve trafficability. South African ores typically have 60 to 80% passing the 200µ with less than 10% clay sized particles. A typical example of a grading curve is shown on Figure 14. Very little clay minerals occur in the clay-sized particle fraction of the tailings.

6.3 French Experience

Dry tailings are both being produced and handled at the Compagnie Minière Dong-Trieu Mine in France. The tailings product being placed is a mixture of de-watered tailings and de-watered thickener underflow from the other plant streams in the ratio of 40 to 7.

The grading for the tailings produced is shown on Figure 14. A grading for the thickener underflow could not be obtained, but this is understood to be 100% minus the #325 sieve.

After belt filtering, the two products are reduced to moisture contents of 35% and 65% respectively. These products are discharged onto a common belt conveyor and conveyed to a stockpile where the products become, naturally, intimately mixed to yield an average moisture content of 45%. At this high moisture content the tailings pile slump to a low side angled cone of about 6 to 7°.

The stockpile area is under-drained but the drainage system appears to be effectively blinded as no seepage discharge was observed from the system.

Tailings are loaded, using front-end loaders, into trucks for haulage to the disposal area. The sloppy tailings are being effectively handled in this manner, but some spillage does occur and the tailings cannot support vehicles at either the loading or unloading locations.
Tailings are discharged by end tipping into large dyked cells, approximately 15m (50ft) deep, formed with waste rock from the open pit mine. The tailings form a shallow fan radiating away from the tip location. To advance the top edge, waste rock is placed on and with the tailings. Once a cell is full it is allowed to dry covered with waste rock and reclaimed. Apparently, no difficulties have been experienced with radionuclide migration due to surface runoff or seepage, demonstrating the effectiveness of clay tailings for pollution control.

The Dong-Trieu tailings disposal demonstrates that even fairly sloppy tailings can be effectively handled by conventional earth moving equipment. Despite this it is believed that the disposal methods could be considerably improved provided the handleability of the tailings could be improved.

The simplicity of the current disposal method appears to indicate that it must also be economically effective.

6.4 Conditions and Trends in Canada

Conditions in Canada are different in many respects to those which prevail in France, South Africa and the U.S.A. The climate is generally harsher and natural precipitation is fairly high while evaporation may be low in regions. Mining operations are often carried out in environments which receive more precipitation than can be gotten rid of by natural evaporation. Generally there has been no incentive to use water sparingly.

Open processing circuits and unrestrictive use of water are factors which have received much attention from regulatory authorities as new projects are designed and proposals for their development come up for review and approval. The arguments in favour of making changes to produce 'dry tailings' (from coal washing plants and from uranium plants) are suggestions that: (i) better technology may be developed which will result in cleaner operations, and, (ii) the overall economics may be found to be more favorable than existing systems.

To a large extent the production of dry tailings in Canada will depend on the successful adaptation of mechanical methods which can be integrated and controlled as part of the process plant. Coal and uranium have been chosen because they present vastly different problems and they are both areas in which we have considerable experience. Coal involves mainly physical processing while uranium plants are based on a much more complex series of chemical operations. Waste products from both have to be dealt with in a manner which complies with tight environmental standards and these are changing continually. Better technology will become mandatory.
7. **CONCLUSIONS**

Based on our work, which has included visits to coal and uranium operations in the countries indicated, as well as direct involvement with projects in Canada and the U.S.A. the main conclusions are:

- **Production of dry tailings is technically feasible and economically viable on some operations.** There are installations which have demonstrated this conclusively.

- **The technology and equipment for dry tailings systems are developing very rapidly.** Increased equipment sizes and optimization of use is continually improving the methodology and economics.

- **Implementation of dry tailings schemes provide considerable advantages for both the short and long-term limitation of environmental impacts of mine and milling operations.** In some cases it is also possible to increase the overall yield of the product and improve the economics of the project.
### 8. REFERENCES

<table>
<thead>
<tr>
<th>Author(s)</th>
<th>Title</th>
<th>Source</th>
</tr>
</thead>
<tbody>
<tr>
<td>Yancey H. &amp; Geer M</td>
<td>&quot;Behavior of Clays Associated With Low-Rank Coals in Coal-Cleaning Processes&quot;</td>
<td>Bureau of Mines RI 5961</td>
</tr>
<tr>
<td>Von Michaelis H (1979)</td>
<td>&quot;Belt Filtration for Uranium Mills&quot;</td>
<td>Symp. on Uranium Mill Tailings Management, Colorado State University</td>
</tr>
<tr>
<td>Purchas DB (1972)</td>
<td>&quot;Cake Filter Testing &amp; Sizing: A Standardized procedure&quot;</td>
<td>Filtration &amp; Separation, 10, 161-171, 228</td>
</tr>
<tr>
<td>Mbir DN &amp; Read AD (1975)</td>
<td>&quot;Filtration of Slurries&quot;</td>
<td>Report SPS/SAR4 6531, Mineral Processing Div. Dept. of Industry, Great Britain</td>
</tr>
<tr>
<td>Lambe TW (1967)</td>
<td>&quot;Soil Testing for Engineers&quot;</td>
<td>John Wiley &amp; Sons</td>
</tr>
<tr>
<td>Nowatzki EA (1982)</td>
<td>&quot;The Use of Mobility Analyses for the Selection of Heavy Mining Equipment&quot;</td>
<td>to be presented at Purdue Conference on Construction Equipment 1982</td>
</tr>
<tr>
<td>Karafiath LC &amp; Wade RL</td>
<td>&quot;Mobility Analyses of Bucket Wheel Excavators Operating on Copper Mill Tailings&quot;</td>
<td>to be published in AIME Journal shortly</td>
</tr>
<tr>
<td>Robertson A. MacG (1980)</td>
<td>&quot;De-Watering Coal Refuse&quot;</td>
<td>Coal Age, May 81, pp 145-157</td>
</tr>
<tr>
<td>Robertson A. MacG</td>
<td>&quot;Refuse Sludge De-Watering at Martin County Coal Corp., Inez, Kentucky&quot;</td>
<td>Kentucky Mining Inst., Nov 7, 1980</td>
</tr>
</tbody>
</table>