The evaluation of five flowsheets for the recovery of uranium from Witwatersrand leach pulps

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SYNOPSIS

A flowsheet incorporating rotary-drum filtration for the solid–liquid separation step, followed by solvent extraction for uranium purification, is used as a standard against which four flowsheets are compared. These flowsheets employ either countercurrent decantation or belt filtration for solid–liquid separation, and either solvent extraction or continuous ion exchange plus solvent extraction for the purification step. Sales revenue, taxation, capital expenditure, and operating costs are estimated. These factors are taken into account in the calculation of an incremental net present value for each circuit by the discounting of cash flows at 25 per cent per year over a projected life of 15 years.

For the material used in these examples, the highest net present value results from the circuit that employs belt filtration followed by continuous ion exchange and solvent extraction.

SAMEVATTING

'n Vloeidiagram wat draaitrommelfiltrasie vir die skeiding van die vastestof en vloeistof, gevolg deur suiwering met oplosmiddelekstraksie vir uraan insluit, word gebruik as 'n standaard waarmee vier vloeidiagramme vergelyk word. Hierdie vloeidiagramme gebruik teenstroom-afgieting of bandfiltrasie in die vastestof/vloeistofskeidingstap, en oplosmiddelekstraksie, of deurlopende ioonuitruiling plus oplosmiddelekstraksie, vir die suiweringstap. Die inkomste uit verkope, belasting, kapitaaluitgawes en bedryfskoste word beraam. Hierdie faktore word in aanmerking geneem by die berekening van die netto huidige waarde van elke kring deur die verdiskontering van die kontantvloei teen 25 persent per jaar oor 'n lewensduur van 15 jaar vir die projek.

Die hoogste netto huidige waarde is verkry vir die kring wat gebruik maak van bandfiltrasie, gevolg deur deurlopende ioonuitruiling plus oplosmiddelekstraksie in die besondere geval van die materiaal wat in hierdie voorbeelde gebruik is.

Introduction

A large number of factors affect the viability of a new venture for the production of uranium. The source, quantity, and grade of the feed material are primary considerations, but the presence of other valuable materials in the ore may be of overriding importance. In particular, whether the uranium is a by-product or a co-product of gold recovery will determine whether the uranium revenue should bear a proportion of the costs of mining and milling in addition to the costs of uranium extraction and recovery. When low-grade material is considered, the profitability of uranium production is critically dependent on the levels of capital and operating costs associated with the extraction and recovery operations. This paper presents a method by which alternative metallurgical flowsheets can be evaluated on a realistic basis.

The examples used to illustrate the evaluation method deal with the recovery section of a uranium plant. The recovery section was chosen for detailed consideration because it includes the operations of solid–liquid separation and uranium purification, which at present offer the greatest variety of interacting choices to the plant designer. The data used in the analysis of these flowsheets do not correspond to those of any particular mine or property, but have been chosen as typifying the response of Witwatersrand material. The final ranking of the possible flowsheets is a function of both the grade and the amenability of the material to the process operations. Thus, the flowsheet chosen in one situation is not necessarily that best suited to another.

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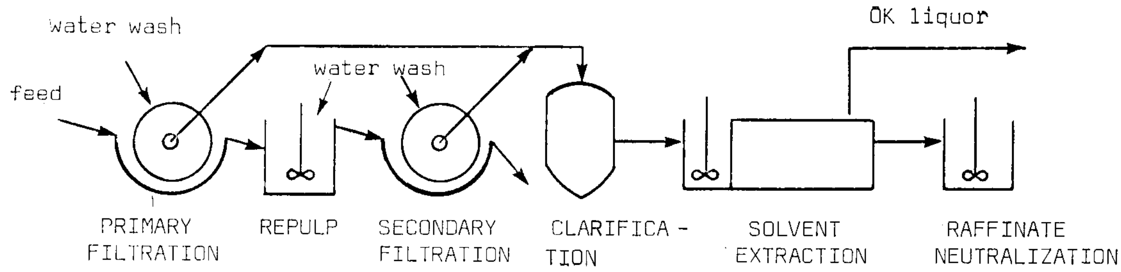
Possible Flowsheets

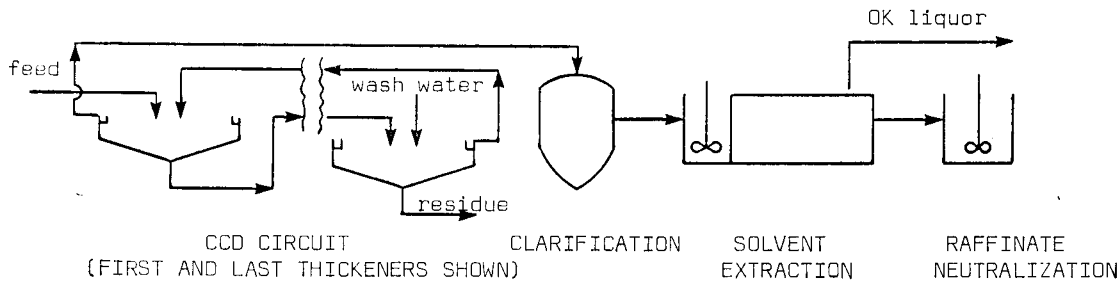
The seventeen uranium plants commissioned in South Africa between the years 1952 and 1957 all featured two stages of rotary-drum filtration, followed by fixed-bed ion exchange. After the Purlex solvent-extraction process had been proved at Buffelsfontein in 1966, a number of the plants then still operating modified their flowsheets by substituting solvent extraction for fixed-bed ion exchange. The solvent-extraction route was chosen for the President Brand uranium plant, which was completed in 1971, and for the uranium section of the ERGO complex. In this paper rotary-drum filtration followed by solvent extraction (Flowsheet 1) is taken as an appropriate standard against which alternative processes can be compared.

The most recent uranium plant to come on-line in South Africa is the extension to the plant at Blyvooruitzicht for the treatment of dump material. This flowsheet incorporates countercurrent washing in thickeners (CCD) in place of rotary-drum filtration. Laboratory and pilot-plant work undertaken by the Extraction Metallurgy Division of the Atomic Energy Board, in close collaboration with Rand Mines Limited, provided the basis for the sizing of these thickeners. The successful commissioning of this plant has proved that CCD is a viable alternative to filtration for Witwatersrand acid-leach pulps. Flowsheets 2 and 3 employ CCD in the solid–liquid separation step.

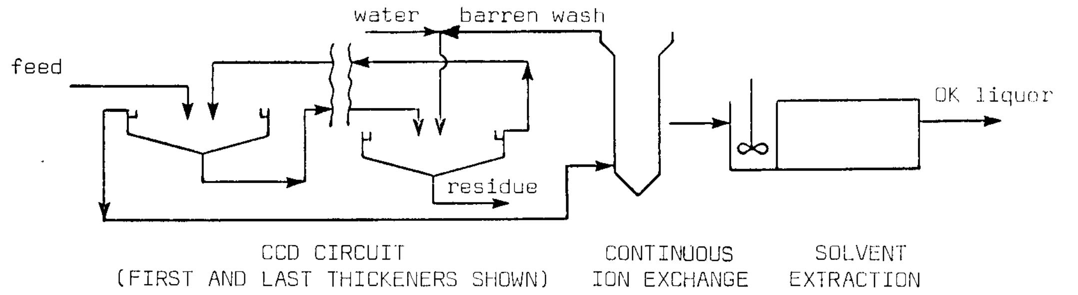
Although horizontal-belt filters have been used in the process industries for a number of years, their introduction into the uranium industry was relatively recent. In 1973 a 12,5 m^2 belt filter was installed at the Forez plant in France, and its satisfactory performance led to the specification of belt filters in a number of French-



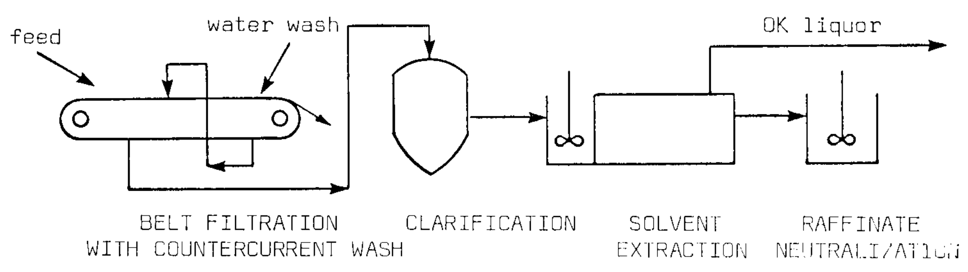
Flowsheet 1—Rotary-drum filtration (RDF) and solvent extraction (SX)



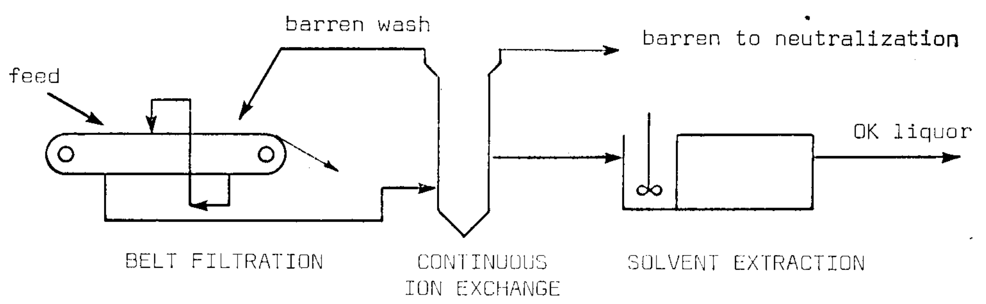
Flowsheet 2—Countercurrent decantation (CCD) and solvent extraction (SX)



Flowsheet 3—Countercurrent decantation (CCD), continuous ion exchange (CIX), and solvent extraction (SX)



Flowsheet 4—Belt filtration (BF) and solvent extraction (SX)



Flowsheet 5—Belt filtration (BF), continuous ion exchange (CIX), and solvent extraction (SX)

designed uranium plants. A significant development in this field was the installation and testing of a 120 m^2 belt filter at the Millsite uranium plant at Randfontein. Belt filters are used for the solid–liquid separation step shown in Flowsheets 4 and 5.

The Purlex solvent-extraction process has two major disadvantages when applied to uranium processing. First, an expensive clarification step is required to reduce the suspended solids in the feed to the low levels required by the solvent-extraction process. Second, because the operating costs of a solvent-extraction plant are proportional to the volumetric feed rate, the costs of treatment per unit of uranium throughput are high when the concentration of the uranium in the feed solution is low. These considerations have provided the motivation in a number of countries for the development of equipment for continuous ion exchange that is capable of treating unclarified solutions. The South African development programme is described in detail in a paper by Haines[1]. The use of continuous ion exchange followed by a small solvent-extraction plant as shown in Flowsheets 3 and 5 affords many of the benefits of both recovery processes.

Material Balance and Process Design

The recoveries achieved in a closely controlled laboratory or pilot-plant test programme may prove difficult to maintain year after year on a full-scale production plant. For this reason, the process parameters chosen for the comparison of the five flowsheets given in the previous section is conservative rather than optimistic.

The basis of the comparison is a leaching plant treating 270 000 tons of solids per month to produce a leach pulp of 1,65 relative density, which is equivalent to a monthly output of 161 460 tons of leach liquor containing 0,322 kg/m^3 of soluble U_3O_8. For the flowsheets incorporating ion exchange, this value is increased to 0,324 kg/m^3 by the recycling of solutions from the ion-exchange and solvent-extraction sections.

The filter cake is assumed to have a moisture content of 27 per cent for both types of filters. The design duties are 6,5 t/m^2 per day for the rotary-drum filters and 11,9 t/m^2 per day for the belt filters.

The CCD thickeners are based on an area requirement of 0,186 m^2/t for 24 hours. In the calculation of the soluble loss, it was assumed that the thickener stage efficiency was 95 per cent, i.e., the grade of the overflow solution from a thickener was 0,95 times that of the underflow, and that all underflows had a solids content of 50 per cent. Table I compares the material balance for the five flowsheets.

Capital Costs

The capital costs of each flowsheet were estimated on the basis of detailed lists of equipment. In addition to the values for the major equipment, the values for all the intermediate tanks, sumps, reagent storage and distribution systems, pumps, and buildings were estimated separately. Piping, valves and fittings, instrumentation, and electrical work were allowed for by the use of appropriate factors. The estimates include an overall contingency allowance of 10 per cent and an

TABLE I

COMPARISON OF MATERIAL BALANCES

Flowsheet no. and type	1 RDF+SX	2 CCD+SX	3 CCD+CIX+SX	4 BF+SX	5 BF+CIX+SX
Solid–liquid separation					
No. of stages*	2	5	5	1(2)	1(2)
Wash ratio**	0,811	2,402	2,402	3,168	3,168
Preg: solids ratio†	1,125	2,000	2,000	1,400	1,400
Soluble loss‡, %	2,50	1,76	2,19	2,00	2,49
Concentration and purification					
U_3O_8 in pregnant solution, kg/m^3	0,167	0,095	0,097	0,135	0,137
U_3O_8 in CIX barren, kg/m^3	—	—	0,002	—	0,002
U_3O_8 loss in barren, %	—	—	nil	—	0,24
U_3O_8 in SX raffinate, kg/m^3	0,0005	0,0005	0,0005	0,0005	0,0005
U_3O_8 loss in raffinate, %	0,30	0,52	nil	0,37	nil
Overall recovery of U_3O_8 from solution, %	97,20	97,72	97,81	97,63	97,26

*Each belt filter has one stage of filtration and two stages of countercurrent wash.
**In tons of liquid added as wash per ton of solution accompanying the solids leaving each stage (excluding RDF repulp water).
†In tons of pregnant solution per ton of solids feed.
‡In kilograms of dissolved U_3O_8 accompanying the washed solids per kilogram of U_3O_8 in the leach liquor.

TABLE II

SUMMARY OF TYPICAL COSTS IN ARBITRARY UNITS

Flowsheet no. and type	1 RDF+SX	2 CCD+SX	3 CCD+CIX+SX	4 BF+SX	5 BF+CIX+SX
Labour	549	377	377	370	370
Reagents	5521	8145	5018	6716	4895
Maintenance supplies	2025	1883	1636	1565	1460
Power	849	179	179	664	664
Total	8944	10584	7210	9315	7389

additional 16 per cent to cover engineering-design and management fees. On an absolute basis, the accuracy of these study estimates cannot be expected to be much better than 30 per cent. However, on the comparative basis on which the cost estimates are used in the following analysis, only the relative errors are significant. These relative errors are probably within 10 per cent of the total cost values.

Because working capital is assumed to be the same for each example, it is omitted from the incremental calculations.

Operating Costs

The operating costs were estimated from a detailed breakdown of the components of labour, reagents, and power. Maintenance supplies were estimated as 4 per cent of the capital cost excluding fees. The recovery plant's share of general overheads (for example, office and laboratory services) was excluded. The operating costs per ton of material treated are summarized in Table II.

Cost Comparisons

There is often a trade-off between capital and operating costs in the design of metallurgical plant: the lower the capital cost, the higher the operating cost. Moreover, recovery efficiencies may differ. Therefore, for the comparison of a number of flowsheets to be realistic, a method has to be used by which these three factors can be combined into a single figure.

A primary step in this direction requires the calculation of the after-tax cash flow that will occur in each year to the end of the life of the project. Two methods are often employed to reduce a series of cash flows to a single figure. The first requires the calculation of the discount rate that will result in the sum of the discounted cash flows being equal to zero. The second applies a chosen discount rate to the cash flows. In this case the sum of the discounted cash flows, known as the net present value (NPV), will not normally be zero, but will be equal to some positive or negative value. Different projects are valued according to the magnitude of their NPVs. An adaptation of this method is used here.

Before the five flowsheets can be compared, the CCD circuits have to be optimized with respect to wash ratio and number of thickeners. Material balances were calculated for circuits containing three, four, five, and six thickeners coupled with continuous ion exchange and solvent extraction (Flowsheet 3) at liquid: solid ratios of 2,0 and 3,0. Table III is a summary of the resulting soluble losses, revenue, capital costs, operating costs, and NPVs, all shown as increments on the basic case of three thickeners with a liquid: solid ratio of 2.

A uranium selling price of U.S. $40 per pound of U_3O_8 (R76,68 per kilogram of U_3O_8) was assumed in the calculation of the revenues. An allowance was added to the operating costs to cover calcining, sales, and other costs payable ex-plant.

The last line of Table III gives the incremental NPVs calculated from the cash flows for a discount rate of 25 per cent per year over fifteen years, the values in brackets indicating negative quantities. The highest NPVs occur at the lower liquid: solid ratio of 2,0. The difference of R10 000 in the NPV between the four- and five-stage circuits is not significant. The optimum choice is therefore a five-stage circuit operated at a liquid: solid ratio of 2,0.

A similar procedure was employed in the evaluation of the five flowsheets, Flowsheet 1 (rotary-drum filtration followed by Purlex) being chosen as the basic example and the NPVs being calculated as increments on the basic example.

Table IV is a specimen calculation of the incremental values obtained when the values for Flowsheet 1 are subtracted from those of Flowsheet 5. The resulting incremental cash flows discounted at 25 per cent per year yield the incremental NPV. A tax charge of 68 per cent of operating profit less 6 per cent of revenue was assumed to cover all the leasing and taxation charges in this example. The capital expenditure is subtracted from the operating profit in the initial years to give the taxable profit without the carrying forward of interest on unredeemed capital. In practice, the particular tax situation applicable to the mine under consideration should be applied.

Table V summarizes the values required for the calculation of incremental NPVs for each flowsheet. A comparison of these NPVs allows a ranking to be made of the flowsheets in terms of this measure of profitability.

Discussion

In the analysis presented here, Flowsheet 5 (belt filters, ion exchange, and solvent extraction) yields the highest NPV. This is also the flowsheet with the lowest capital and operating costs. The recovery of uranium, however, is relatively low. The availability of capital and the level of profitability judged to be appropriate to the circumstances that attend a proposition may in-

TABLE III

COST COMPARISONS

Liquid:solid ratio	2,0				3,0			
Number of stages	3	4	5	6	3	4	5	6
Soluble loss, %	6,90	3,58	2,19	1,56	3,42	1,82	1,30	1,14
Incremental production of U_3O_8, kg/a	Nil	20 770	29 516	21 707	21 707	31 780	34 982	35 997
Incremental revenue, R/a ($\times 10^3$)	Nil	1 593	2 263	2 563	1 665	2 437	2 682	2 760
Incremental capital costs, R ($\times 10^3$)	Nil	1 423	2 848	4 272	3 044	4 469	5 893	7 315
Incremental operating costs, R/a ($\times 10^3$)	Nil	193	363	527	214	387	547	705
Incremental NPV, R($\times 10^3$)	Nil	1 370	1 360	678	460	552	(211)	(1 413)

fluence the interpretation of a cash flow calculation. For example, Flowsheets 3 and 4 have similar NPVs. For these two flowsheets, belt filters and solvent extraction result in the cheaper plant, whereas the plant for CCD, ion exchange, and solvent extraction has lower operating costs. Surprisingly, these NPVs were found to be relatively insensitive to changes in the chosen discount rate.

The flowsheet serving as the basic example and the flowsheet for CCD and solvent extraction show little difference in profitability. The saving in capital costs of the latter flowsheet and the higher uranium recovery are largely offset by the higher operating costs.

The long-term maintenance costs of belt filters are uncertain, and may prove different from the uniform allowance of 4 per cent of capital cost that was used in the calculation of the operating costs. On the other hand, the duty assumed for the belt filters in these examples may be exceeded with many ores. If the price of uranium rises at a faster rate than that of the cost factors, Flowsheets 2, 3, and 4 will be more economical than Flowsheets 1 and 5, which have a somewhat lower recovery. All these factors, and many more, could disturb the ranking of flowsheets given in Table V. Perhaps the only conclusion that is generally valid is that the newer flowsheets now being considered for the recovery of uranium offer potential advantages over those of the uranium plants built in South Africa before the present expansion in the commercial uranium market.

TABLE IV

EXAMPLE OF INCREMENTAL NPV CALCULATION FOR FLOWSHEET 5

	Year 0	Years 1 to 15
Incremental revenue, R/a		30 000
Incremental operating costs, R/a		(500 000)
Incremental operating profit, R/a		530 000
Incremental capital cost, R	(7 764 000)	
Taxable amount, R/a	7 764 000	530 000
Tax:		
68 % of taxable amount, R/a	5 279 520	360 400
Less 6 % of revenue, R/a	Nil	1 800
Total tax, R/a	5 279 520	358 600
Net cash flow, R/a	2 484 480	171 400
NPV at 25 % p.a. over 15 years, R	3 146 000	

Acknowledgement

The permission granted by the Atomic Energy Board, General Mining and Finance Corporation Limited, and the Nuclear Fuels Corporation to publish this paper is gratefully acknowledged.

Reference

1. HAINES, A. K. The development of continuous fluidized-bed ion-exchange in South Africa, and its use in the recovery of uranium. *J. S. Afr. Inst. Min. Metall.*, to be published.

TABLE V

SUMMARY OF THE EVALUATION OF PROFITABILITY

Flowsheet no. and type	1 RDF+SX	2 CCD+SX	3 CCD+CIX+SX	4 BF+SX	5 BF+CIX+SX
Overall recovery of U_3O_8 from each solution into OK liquor	97,20	97,72	97,81	97,63	97,26
Incremental revenue, R/a ($\times 10^3$)	nil	254	298	210	30
Incremental operating costs, R/a ($\times 10^3$)	nil	698	(361)	125	(500)
Incremental NPV at 25 % p.a. over 15 years, R($\times 10^3$)	nil	324	2313	2260	3146

NIM reports

The following reports are available free of charge from the National Institute for Metallurgy, Private Bag, X3015, Randburg, 2125 South Africa.

Report no. 1876

The ultrasonic determination of the mud level in a thickener and the resin level in an ion-exchange column. (11th Nov., 1977).

Two ultrasonic instruments having the same principle of operation were evaluated as detectors for the mud level in a thickener and the resin level in an ion-exchange column.

The Hecta echo sounder, a ship's echo sounder that had been converted by the factory to have a range between 0,4 and 3 m, operated well for detection of the mud level in a thickener but was unable to operate in a resin column. The Wesmar interface detector, which was specifically designed for mine installations, operated well in the thickener and in a resin column.

An optical probe was constructed for calibration in a thickener, but was not used in the resin column because there were grids inside the column that, at certain times, were exposed when the level of the resin fell, and hence these were used for calibration.

Report no. 1911

Methods of analysis for zinc-bearing materials, electrolytes, and process solutions. (2nd Dec., 1977).

Methods are proposed for the analysis of the solids and solutions encountered in the production of metallic zinc. With the exception of germanium, the metallic trace constituents are determined by instrumental techniques, namely various modes of atomic-absorption spectrophotometry and optical-emission spectrography. Ion-selective electrodes are used for the determination of chloride, fluoride, and ammonium ions, whereas germanium is determined spectrophotometrically. The choice of technique for certain analyses is discussed briefly.

National service

A considerable amount of misapprehension exists amongst students and graduates regarding the approach of the S.A. Defence Force towards the training of engineers during their period of national service in the defence force. To obtain clarity, the S.A. Council for Professional Engineers asked for discussions with the Defence authorities, and the following summary is made available for general information.

University Training

(1) *Undergraduate Study*

It has again been reaffirmed that prospective students should preferably undertake their studies first and obtain their first degree prior to undergoing national service. It is, however, expected that these studies be completed in the shortest possible time, i.e., four years for the engineering degree.

Should this not be possible, postponement, duly supported by the university, will be granted on request for a maximum of a further two years, but application must be made *each year*. All cases are considered on merit, and postponement is not granted automatically. Where a change of the course of study is made, postponement will not be granted except in exceptional cases.

(2) *Post-graduate Study*

Postponement for post-graduate study will normally not be granted, but deserving cases will be considered on merit.

Where trainees undertake private study, their attention is directed to the fact that no special arrangements for study time or facilities can be granted, but attendance of a short course or courses of up to three weeks per year may be possible. Should the course be of particular importance to the Defence Force, further concessions may be considered.

(3) *Diploma Study*

Postponement of national service may, on request, be obtained for the duration of the N.D.T. Course at a College for Advanced Technical Education. Where a diploma student at a College for Advanced Technical Education wishes to change to a degree course, postponement may be requested and, if the merits of the case justify postponement, this may be granted.

Military Training

(1) *Basic Training*

To function effectively in any given working environment, a degree of orientation is necessary, and in the Defence Force this time is of utmost importance because a graduate must understand all the elements concerning men, money, and machines. This period is directed mainly at the first of these three. SACPE sees this experience as acceptable within the framework of the total training.

(2) *Engineering Training*

Services trainees will, where possible, be placed on military projects of an engineering nature, after completion of the basic training. Should this not be possible, they will be placed with other state or semi-state organizations where they will work under civilian engineers. The object is that trainees will not perform this service with their employers.

General

(1) *Reporting*

It is important that all trainees, upon reporting for service, clearly state their registration as engineers in training so that they can be placed in the correct type of unit.

(2) *Communication*
Where it becomes necessary to discuss service or to solve other problems, the procedure to be followed is, in the first instance, to contact the immediate officer in charge and, should the matter be one of engineering training, then, one month after it has been discussed with the commanding officer, to write to the Chief of Staff, Personnel, Private Bag X159, Pretoria, attention D.P.O., with a proper explanation of the problem and the steps already taken.
Prior to the placing of trainees, requests for postponement can be forwarded to the Exemptions Board direct.

Nasionale diensplig

Daar bestaan heelwat onduidelikheid onder studente en graduandi in ingenieurswese oor die benadering van die S.A. Weermag ten opsigte van opleiding van ingenieurs in die Weermag gedurende hulle tydperk van nasionale diensplig.

Om duidelikheid te verkry het die Suid-Afrikaanse Raad vir Professionele Ingenieurs aangevra vir samesprekings met die Weermag en die volgende inligting kan kortliks beskikbaar gestel word.

Universiteit Opleiding

(1) *Voorgraadse studie*
Dit is weereens bevestig dat voornemende studente liewers eers moet studeer en hulle eerste graad behaal voordat hulle hul nasionale diensplig ondergaan. Dit word egter verwag dat die studie in die kortste tyd voltooi word, d.w.s. vier jaar vir die ingenieursgraad.
Indien dit nie moontlik is nie word uitstel op versoek en behoorlik ondersteun deur die universiteit, toegestaan tot 'n maksimum van 'n verdere twee jaar maar aansoek moet *elke jaar* gedoen word. Alle sake word op meriete behandel en uitstel word nie outomaties toegestaan nie. Waar van studierigting verander word, word uitstel nie toegestaan nie, behalwe in besondere gevalle.

(2) *Nagraadse studie*
Uitstel vir nagraadse studie word normaalweg nie toegestaan nie, maar verdienstelike gevalle mag op meriete oorweeg word.
Waar dienspligtiges private studie onderneem, word hulle aandag daarop gevestig dat geen spesiale vergunnings ten opsigte van studietyd of fasiliteite toegestaan kan word nie, maar bywoning van 'n kort kursus of kursusse tot 3 weke per jaar mag moontlik wees. Indien die kursus spesifiek van belang vir die Weermag is, kan verdere toegewings oorweeg word.

(3) *Diploma studie*
Uitstel van nasionale diensplig kan vir die duur van N.D.T.-kursusse aan 'n Kollege vir Gevorderde Tegniese Onderwys op aansoek toegestaan word. Waar 'n diplomastudent by 'n Kollege vir Gevorderde Tegniese Onderwys wil oorslaan na 'n graadkursus mag uitstel aangevra word en indien die meriete van die saak dit regverdig kan daarvoor ook uitstel toegestaan word.

Diensplig Opleiding

(1) *Basiese opleiding*
Om in enige werksomstandighede effektief te funksioneer is sekere oriëntering nodig en in die Weermag is hierdie tyd van uiterste belang want 'n gegradueerde moet al die elemente van mense, middele en masjiene verstaan. Hierdie tydperk het veral te doen met die eerste van hierdie drie aspekte. SARPI sien hierdie ervaring as toepaslike ervaring binne die raamwerk van die geheelopleiding.

(2) *Ingenieursopleiding*
Dienspligtige ingenieurs sal waar moontlik op militêre projekte van 'n ingenieursaard aangewend word na voltooiing van die basiese opleiding. Waar nie moontlik nie sal hulle geplaas word by ander staats- of semi-staatsinstansies waar hulle onder burgerlike ingenieurs sal werk. Die doel is dat die dienspligtiges nie by hulle werkgewers hierdie diens verrig nie.

Algemeen

(1) *Aanmelding*
Dit is noodsaaklik dat alle dienspligtiges by aanmelding hulle registrasie as ingenieur-in-opleiding duidelik meld sodat hulle in die regte soort eenheid geplaas kan word.

(2) *Kommunikasie*
Waar dit nodig is om diens te bespreek of probleme op te los is die prosedure om eerstens met die onmiddellike bevelvoerder te skakel en indien die saak ingenieursopleiding raak mag daar, 'n maand nadat dit met die bevelvoerder bespreek is, aan die Hoof van Staf, Personeel, Privaatsak X159, Pretoria, vir aandag D.P.O., geskryf word met 'n behoorlike uiteensetting van die probleem en die stappe wat reeds geneem is.
Voordat dienspligtiges ingedeel is, kan versoeke vir uitstel direk aan die Vrystellingsraad gerig word.

Book reviews

M. Sittig. *Particulates and fine dust removal. Processes and equipment*. Park Ridge (U.S.A.), Noyes Data Corporation, 1977. 600 pp. $48.

This publication is a veritable encyclopaedia that covers the health, aesthetic, and economic problems arising from pollution of the atmosphere by particles from industrial and other sources. It records how environmental pollution became a public issue in the U.S.A., culminating in the Clean Air Act of 1967 and in the establishment of the Environmental Protection Agency in 1970. By 1974 this Agency had recorded a number of national standards.

This volume records, on a national basis, the estimated emissions from operations involving the combustion of fuel, the crushing of stone, sand, and gravel, agriculture, iron and steelmaking, and fourteen lesser-industrial sources. Non-industrial sources, such as forest fires, litter and agricultural burning, motor vehicles and aircraft, cigarette smoke and aerosols, are analysed in detail, with a total well in excess of the industrial sources. The non-industrial data were supplied by eighteen widely spaced recording stations in the U.S.A.

Under twenty industrial headings, the emission sources and rates, the control processes, the problems, and the results are recorded in full detail for each industry.

'How to reduce such emissions at the source and what processes and equipment to use' were the publishers' objectives, and these have been ably achieved in this volume.

H.B.

C. D. Storrar. *South African mine valuation*. 1977.

This long-awaited comprehensive volume on mine valuation fulfils every promise and expectation. It deals competently with all aspects in this field, from the attitude of the State to mining enterprise in South Africa, emphasizing the corner-stone to disposal of the final product and assessing the profits and the State's share in terms of lease consideration and taxation.

Details of the investigation required before embarking on a mining venture are well presented. The prerequisite of reliable sampling data, which enable accurate assessments and forecasts to be made, is evident for all mining projects, all the calculations being based on this information. Senior personnel involved in this field should give particular and continuous attention to this aspect.

The section devoted to ore reserves is particularly well presented, and will be of great value to all concerned when it is appreciated that the volume and value of the reserves are the life-blood of a mine.

The progress made in recent years in the field of statistical mine valuation is given prominence, and should be of international interest to all mining engineers and investors. It is pleasing to note that the contents are based entirely on the rationalized and standardized form of the SI system, and, as such, is a 'world first' that should make the issue a most sought-after volume in the international market.

The author and his dedicated committee of mine surveyors are to be commended on having produced an outstanding work which should find a place in the libraries of all who are interested in mining.

D.G.M.

Tunnelling '76. London, Institution of Mining and Metallurgy, 1977.

This book contains the 35 excellent papers, with discussions and authors' replies, that were presented at an international symposium held in London in March 1976. The papers include contributions from civil engineers, mining engineers, and geotechnologists.

The subjects covered include the following:

(a) site investigation and geotechnical considerations;
(b) hard-rock excavation, including tunnelling machines;
(c) soft-ground tunnelling;
(d) support;
(e) experimental tunnels, and field measurements in tunnels.

The international flavour of the symposium is illustrated by the fact that the papers embraced tunnelling in the following countries:

United Kingdom	Hungary	New Zealand
France	Switzerland	Japan
Germany	India	Russia
Italy	Finland	Australia
Sweden	Costa Rica	South Africa.

It is of interest to note that no fewer than 27 (or 80 per cent) of the papers concern hard-rock tunnelling, and it is significant that 50 per cent of the papers deal with tunnelling machines. The key-note address was given by Richard J. Robins, President of the Robins Company U.S.A., who detailed the progress made in overcoming problems in hard-rock tunnelling and admitted that much still remains to be solved. Progress has been made in this field by the research team of the Colorado School of Mines.

Other subjects covered at the symposium included controlled blasting, smooth blasting, rockbolting, support of tunnels at depth, and a new approach to steel support at depth.

Many of the authors pointed to the need to collect the fullest possible geological and geotechnical information before embarking on a tunnel project. A paper on the planning of the North Sea tunnel project is of particular interest.

This volume of proceedings is in the nature of a text-book and should be included on the bookshelves of all engineers engaged in tunnelling.

D.G.M.