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RECENT TRENDS IN RESEARCH AND DEVELOPMENT WORK ON THE PROCESSING OF URANIUM ORE IN SOUTH AFRICA

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ATOMIC ENERGY BOARD
Pelindaba
PRETORIA
Republic of South Africa

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The contents of this report were presented in a paper to the IAEA Advisory Group Meeting on Uranium Ore Processing, the proceedings of which will be published by the IAEA.

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CONTENTS

SAMEVATTING

Die belangrike rol wat uraan in die oplossing van die wêreld se energieprobleme sal vervul, en die behoefte aan voortgesette navorsings- en ontwikkelingswerk op hoë vlak betreffende die verwerking van uraanerts, word in Suid-Afrika deeglik besef.

Die vinnige styging in die prys van goud en uraan in die afgelope jare het met 'n ongehoorde toename in die bedryfskoste van Suid-Afrikaanse goudmyne saamgeval. 'n Herondersoek van bestaande verloopkaarte vir die herwinning van uraan, goud en piriet uit Witwatersrandse ertse het, in die lig van hierdie ekonomiese neigings, 'n aantal nuttige gebiede vir navorsing en ontwikkeling aangedui.

Die belangrikste aspekte van die verwerking van uraanerts wat tans in Suid-Afrika ondersoek word, is die gebruik van fisiese konsentreermetodes, soos flottering, swaartekragkonsentrering en nat magnetiese skeiding met hoë intensiteit; die wyer toepassing van 'omgekeerde uitloging' waarin vooraf suurloging vir uraan die daaropvolgende ekstraksie van goud verbeter; die gebruik van hoër loogtemperature en hoër konsentrasies van ferri-ioon in die loog om die persentasie geëkstraheerde uraan te verhoog, met inbegrip van die produksie van ferri-ioon uit hersiklusseerde oplossings; die toepassing van drukloging op die herwinning van uraan uit laegraadse ertse en konsentrate; die ontwikkeling van 'n deurlopende ioonruilkontaktor vir die behandeling van verdunde flodders sodat eenvoudiger en goedkoper tegnieke vir vastestof-vloeistofskeiding in plaas van die duur filtrering- en verhelderingstappe gebruik kan word en die verbetering van instrumentasie om byvoegings van swaelsuur en mangaandioksied tot die loog te verbeter.

Die noodsaaklike eienskappe van die nuwe of verbeterde verwerkingstegnieke wat ontwikkel word en belofte van volskaalse aanwending in bestaande of toekomstige uraanaanlëe inhou, word kortliks beskryf.

ABSTRACT

The important role that uranium will play in solving the energy problems of the world, and the need for a continuing high level of research and development activity in the processing of uranium ore, are fully appreciated in South Africa.

The rapid increases in the price of gold and uranium in recent years have coincided with an unprecedented increase in working costs at South African gold mines. A re-examination of the existing flowsheets for the recovery of uranium, gold, and pyrite from Witwatersrand ores, in the light of these economic trends, has resulted in the identification of a number of profitable areas for research and development.

The main topics under investigation in South Africa in the processing of uranium ore are the use of physical methods of concentration such as flotation, gravity concentration, and wet high-intensity magnetic separation; the wider adoption of the 'reverse leach', in which prior acid leaching for uranium improves the subsequent extraction of gold; the use of higher leaching temperatures and higher concentrations of ferric ion in the leach to increase the percentage of uranium extracted, including the production of ferric ion from recycled solutions; the application of pressure leaching to the recovery of uranium from low-grade ores and concentrates; the development of a continuous ion-exchange contactor capable of handling dilute slurries, so that simpler and cheaper techniques of solid-liquid separation can be used instead of the expensive filtration and clarification steps, and the improvement of instrumentation for the control of additions of sulphuric acid and manganese dioxide to the leach.

A brief description is given of the essential features of the new or improved processing techniques under development that hold promise of full-scale application at existing or future uranium plants.

ACKNOWLEDGEMENT

Thanks are due to the many members of staff of the National Institute for Metallurgy, the Extraction Metallurgy Division of the Atomic Energy Board, and the uranium industry, who have been responsible for the work described here and who have assisted the author in compiling this report.

The permission of the Atomic Energy Board, the Nuclear Fuels Corporation of South Africa, and the IAEA to publish this report is gratefully acknowledged.

1. INTRODUCTION

At the last IAEA meeting on this subject in 1970[1], the Panel concluded that, because of the over-supply situation and depressed prices for uranium at that time, the degree of support for research and development on new and improved processing methods was generally low, in spite of predictions of a strong and imminent upsurge in the demand for uranium, and hence for new plant design and construction. It was also noted that, because of the time lag of several years between the proving of new processes and the commissioning of new plants, it would be necessary to give urgent attention to the development and testing of novel ideas if these were to be incorporated in the new plants that would be required during the latter half of the 1970's.

In South Africa, everyone concerned with the processing of uranium ore has fully appreciated the important role that uranium will play in solving the energy problems of the world, and the need for a continuing high level of research activity in this field. Thus, over the last few years the Atomic Energy Board, the National Institute for Metallurgy, and the Nuclear Fuels Corporation of South Africa, have continued to collaborate very actively with mining groups and individual mining companies on uranium research and development.

The purpose of this report is to identify and describe briefly the work being done to improve the processing techniques that hold promise of commercial application in the new treatment plants likely to be constructed in South Africa during the next five years for the recovery of uranium, together with gold and pyrite, from Witwatersrand ores.

2. EXISTING METALLURGICAL CIRCUITS

2.1 INFLUENCE OF CHANGING MARKET CONDITIONS ON THE CONSTRUCTION OF NEW PLANTS

The general pattern for the design of uranium plants in South Africa was set during the comprehensive research and development program of 1946–1956[2]. The first full-scale uranium plant resulting from this program was commissioned in 1952, and by 1957 a total of seventeen plants had been erected. Although a considerable amount of individuality was expressed in the design of these plants, and even though the extent of this individuality increased with later plants, they were all essentially based on the results of this initial research program.

Figure 1 shows how the rapid initial expansion of the industry was dramatically reversed in 1960 by the sudden reduction in the uranium requirements of the Combined Development Agency, an organization representing the governments of the USA and Great Britain, with whom supply contracts for the entire South African uranium output had been concluded in the early 1950's. From 1966, as the prospects for nuclear power began to improve, production gradually picked up when numerous small and often short-term contracts were negotiated with electrical utilities[3]. During 1970–1971, three new plants, at Blyvooruitzicht, West Driefontein, and Western Deep Levels Gold Mines, came into production in anticipation of an upturn in the market, but the expected improved demand did not materialize and the mines were unwilling to continue production at the 1971 level (3 800 t of U_3O_8) in the face of continually falling prices. A fourth new plant, completed in 1971 at President Brand Gold Mine, has only recently been commissioned. The 1975 production will again be of the order of 3 000 t of U_3O_8.

During 1973–1974, there was a spectacular rise in the market price of gold[4] and during the past year a very rapid increase in the price of uranium[5]. In addition, the South African demand for pyrite, associated with the gold and uranium in Witwatersrand ores, is expected to increase very sharply during the next ten years[6]. However, these market changes have coincided with an unprecedented increase in working costs at South African gold mines[7] (see Figure 2). Also, the gold mines take advantage of a higher gold price by mining ore with a lower grade of gold, which generally also means a lower grade of uranium, and the immediate consequence has been a tendency for the uranium output of existing plants to decrease. By-product uranium contributes only a small part of the profits of the combined gold-uranium operation – at present prices the revenue from gold is approximately twenty times that from uranium. The economic feasibility of an expansion in uranium production capacity, particularly for the treatment of low-grade slimes dams, is thus strongly dependent on the development of processes that are cheaper than those employed at present.

2.2 OVERALL RECOVERY PROCEDURES FOR URANIUM, GOLD AND PYRITE FROM WITWATERSRAND ORES

The established procedures for the recovery of uranium, gold, and pyrite from Witwatersrand reefs can be classified[8] into four main types, as shown in Figure 3.

In most of the early uranium plants, acid leaching followed cyanidation (Procedure I), mainly because this involved no change to the existing gold circuits. Prior acid leaching (Procedure II) improves the subsequent extraction of gold (see Section 5 below). On some ores, prior flotation (Procedure III) can be used to produce a concentrate containing up to 80 % of the gold, 80 % of the pyrite, and 25 % of the uranium in less than 10 % of the original mass of ore. Because of the very small mass of this concentrate, it can be milled very finely and treated intensively to yield very high recoveries of gold and uranium. The overall advantage is a saving in milling costs on the bulk of the ore, which does not undergo this intensive treatment. On other mines, the crushed ore is screened (Procedure IV) to achieve a fine fraction (approximately 30 % of the original mass of ore) which contains two-thirds of the gold and more than half of the uranium. This fine fraction is given an intensive treatment, again with an overall saving in milling costs on the bulk of the ore.

2.3 FLOWSHEETS FOR URANIUM RECOVERY

The basic flowsheets used in the design of uranium plants in South Africa can be classified into three main types, as shown in Figure 4.

Flowsheet I was universally adopted for all 17 uranium plants originally constructed. Following pilot-plant demonstration of the Bufflex process[9], the uranium plant at Harmony Gold Mine changed to Flowsheet II. The successful pilot-plant demonstration of the Purlex liquid-liquid extraction process[10] resulted in the conversion of the Harmony plant and five of the seven original plants still in operation at that time, to Flowsheet III, while the four new plants built in 1970–1971 all used this latter flowsheet. Two of the original plants are still operating on the ferric-leach variation of Flowsheet I.

3. MOST PROFITABLE AREAS FOR RESEARCH AND DEVELOPMENT

In the light of the extensive research and development already done in South Africa on the processing of uranium ore, it was not immediately apparent five years ago whether any substantial advances could be made by further research. However, a re-examination, in the light of predicted new developments in metallurgical techniques and economic trends, of the basic decisions taken when the early flowsheets were drawn up, resulted in the following conclusions on the most profitable areas for research.

(a) The full potential of physical methods of concentration such as flotation, gravity concentration, and wet high-intensity magnetic separation, had not been adequately explored for the upgrading of newly mined ores or accumulated slimes with a uranium grade below the cut-off point for 'economically leachable' material.

(b) The increased attention being given by the gold-mining industry to increasing the overall efficiency of gold extraction, indicated that an investigation into the wider adoption of the 'reverse-leach' might have considerable merit.

(c) Reliable experimental data were insufficient for an adequate economic evaluation to be made of increased temperature and ferric-ion concentration in the acid leach, in order to raise the uranium extraction above that conventionally achieved in South Africa. In particular, the full potential of the ferric leach had not been realized at Purlex plants because there were no successful techniques for the recycling of raffinates.

(d) Although the high capital cost of pressure-leaching of Witwatersrand ores had discouraged its introduction in South African uranium plants, the increases in the price of gold and uranium have warranted a re-examination of the process on a pilot scale.

(e) Although the Purlex liquid-liquid extraction process had resulted in significant savings in operating costs over those of the original fixed-bed ion-exchange process, its successful operation required a very clear feed solution. The filtration and clarification steps used to produce this clear solution account for a substantial part of the operating and capital costs of a typical South African uranium plant. There was therefore a strong incentive to develop an alternative system of uranium recovery that would be capable of handling the pulp directly from leaching, or after partial solid-liquid separation. This would eliminate the expensive filtration and clarification steps, or would replace them with simpler and less expensive techniques.

(f) Although extensive use had been made of control instrumentation in the design of existing uranium plants, certain instruments had not performed satisfactorily, and there were substantial benefits to be gained from the development of improved instrumentation to control the additions of sulphuric acid and manganese dioxide to the leach.

4. PHYSICAL METHODS OF CONCENTRATING WITWATERSRAND ORES

4.1 GRAVITY CONCENTRATION AND FLOTATION

The mineralogy of Witwatersrand ores and the initial investigations on the application of gravity concentration and flotation to run-of-mine ores and cyanide residues have been authoritatively described[2, 8, 11, 12]. During the past five years, valuable additional data have been accumulated on the amenability of a large number of ores and residues to these two techniques. More attention to the upgrading of the gold and pyrite content, which occurs as a consequence of their close association with the uranium-bearing minerals, has led to a better understanding of the economic potential of these techniques.

Flotation is being examined as a potential procedure for the commercial treatment of old tailings dumps, and it has been reported that a flotation plant with a monthly feed of one million tons of slimes is to be erected at South African Lands Gold Mine for this purpose[8]. The large capital expenditure required is economically justified by the values of the pyrite, gold, and uranium recovered from these residues, and by the removal, to locations of less value, of old dumps from areas that have become valuable as real estate.

4.2 WET HIGH-INTENSITY MAGNETIC SEPARATION

It has long been known that some of the uranium-bearing components of Witwatersrand ores are feebly magnetic, but serious consideration has only recently been given to magnetic separation as a means of uranium concentration, with the advent of wet high-intensity magnetic separation.

Laboratory results on a large number of low-grade Witwatersrand ores and gold-plant tailings have shown that up to 70 % of the uranium and 50 % of the residual gold can be recovered in a magnetic concentrate representing, in many instances, less than 10 % of the mass of the original feed[13].

The selection of a suitable industrial machine is the next step in the work, and will be followed by large-scale tests at one of the gold mines. Considerable development work appears to be necessary for laboratory results to be reproduced on an industrial-scale machine, but this technique promises to be a major factor in the development of economic methods for the recovery of uranium from very low-grade ores and gold-plant tailings that were previously considered not to be worth treating for uranium.

4.3 COARSE MILLING, GRAVITY CONCENTRATION AND MAGNETIC SEPARATION

Encouraging laboratory results were recently obtained in an investigation aimed at developing a novel procedure for the treatment of Witwatersrand ores[13] (see Figure 5). It is claimed that this procedure not only has all the advantages of Procedure III (Figure 3) as regards reverse leaching and savings in milling costs on the bulk of the ore, but also the following additional attractions:

(a) If a saleable grade of pyrite can be achieved, gravity concentration is a very much less expensive technique than flotation for the recovery of pyrite. (Operating costs for gravity concentration are clearly much lower, since no reagents are required and the capital costs can be as little as one-fifth of those for flotation.)

(b) Intensive treatment of the gravity and magnetic concentrates would result in a very high overall recovery of gold.

(c) The comparatively coarse nature of the gravity tailing would endow the cyanide residue with improved filtration characteristics, and losses of gold in solution would be reduced.

(d) The production and intensive treatment of concentrates of low bulk and acceptable grade could make it possible for uranium recovery to be considered at mines where it is currently thought not to be economically feasible.

5. WIDER ADOPTION OF THE REVERSE-LEACH PROCEDURE

Prior acid leaching of Witwatersrand ores improves the subsequent extraction of gold by exposing the gold locked up in acid-soluble minerals such as uraninite, and in partly soluble silicates like chlorite, and also, it is presumed, by cleaning the surfaces of gold grains by removing films and tarnishes.

Table 1 summarizes the present leaching procedures used by uranium-producing gold mines.

TABLE 1
Leaching Procedures at Current Uranium Plants

Plant	Original plant		Change to reverse leach
	Start-up date	Leaching procedure	
A	1953	Normal	-
B	1953	Normal	1970
C	1955	Normal	-
D	1955	Normal	1957
E	1955	Normal	-
F	1956	Normal	-
G	1956	Normal	1971
H	1957	Normal	1975
I	1970	Reverse	-

Plant D has been successfully operating on reverse leaching since 1957[14], and when new uranium plants were constructed in 1970–1971 at plants B, G and I, the opportunity was taken to introduce reverse leaching.

With the persistent over-supply situation and the depressed uranium prices of the early 1970's, producers still operating on the normal leach were reluctant to consider a changeover to reverse leaching. However, laboratory tests undertaken during 1973 on ore from plant H indicated that the undissolved gold in the final residues could be reduced from 0,49 to 0,24 g/t by the use of reverse leaching. These results were confirmed by pilot-scale tests at the mine, and it was decided to alter the full-scale plant circuit to reverse leaching. The changeover was completed early in 1975, and the results obtained during the first six months of operation confirmed the laboratory predictions. It is estimated that the increased gold revenue to the mine resulting from the changeover will amount to approximately two million rand per annum before tax.

Studies now being undertaken may result in a changeover to reverse leaching at Plants A, C, E, and F if similar benefits in increased gold extraction are indicated by the tests.

6. FERRIC LEACHING AND AUTOXIDATION OF RECYCLED SOLUTIONS

The autoxidation process, in which both sulphuric acid and ferric sulphate can be formed by blowing air and sulphur dioxide into solutions containing ferrous sulphate, was studied during the early stages of the development of the acid-leaching process for the extraction of uranium from Witwatersrand cyanide residues[15]. However, the use of manganese dioxide as an oxidizing agent was later found to be more convenient and economic. Uranium extractions with the manganese dioxide leach are generally about 80 to 85 %.

The use of high concentrations of ferric ions was adopted at two of the seventeen original uranium plants [16]. In these plants, manganese dioxide is replaced as the oxidizing agent by the addition of solutions high in ferric ions obtained mainly by the dissolution, in high-strength sulphuric acid, of the iron oxide sinter obtained from the roasting of pyrite flotation concentrates. Extra ferric ion is obtained by the recycling, via autoxidation with sulphur dioxide, of barren solutions from the fixed-bed ion-exchange plants that are still in operation at these two mines.

Following a comprehensive investigation of the reaction mechanisms and kinetics of the uranium-leaching process[17], and in anticipation of an improvement in the uranium market, laboratory and pilot-plant tests were again carried out in 1970–1971 to evaluate the economics of increasing the temperature and ferric – ion concentration as a means of increasing the uranium extraction to as high as 95 %. Results showed[18] that a 93 % extraction of uranium could be achieved with the so-called Felix leach (64 °C for 24 h with total additions of 6 kg of ferric iron and 14 kg of sulphuric acid per ton of ore).

It was, however, considered necessary to do further work on the testing of improved equipment for the autoxidation of ferrous to ferric ions in recycled plant solutions, and on the problems associated with the filtration of the pulps resulting from a dilute leach high in ferric ions. Difficulties were also envisaged in the recycling of barren solutions from Purlex plants, because of the effect of solvent on the rubber lining of acid-proof pipes and pachucas. Tests were therefore necessary to find techniques for the effective removal of the traces of solvent, to permit the recycling of Purlex barren solutions, via autoxidation, to the leach.

In addition, a spiral heat exchanger had come on the market that appeared to be capable of being used for transferring heat from the hot pulp leaving the last pachuca, to the cold incoming pulp. The successful recovery of this heat would further improve the economics of the Felix leach, and a detailed investigation of the design and performance of this heat exchanger was desirable[19].

Considerable progress has been made in these investigations during the past five years, and the technical and economic feasibility of the Felix leach is being re-evaluated in the light of the increased uranium demand and price, and the use of improved [illegible] autoxidation [illegible] exchange.

[illegible] the [illegible] in South Af[illegible] [illegible] stream of acidified aqueous ferrous sulphate solution is oxidized by a bacterial film in the presence of dissolved oxygen[20]. This technique eliminates the need for sulphur dioxide and is inherently very cheap. Suitable equipment is now being developed for its application on an industrial scale, and, if this is successful, a further substantial reduction in the costs of the autoxidation step, and hence the Felix leach, is envisaged.

It is expected that at least one current uranium producer will change over to a Felix leach, and that the wider application of ferric leaching will take place in due course, with a resultant increase in the overall efficiency of [illegible] extraction.

7. PRESSURE LEACHING OF WITWATERSRAND ORES

The treatment of Witwatersrand ores with air or oxygen at elevated temperatures and pressures results in the decomposition of the pyrite to ferric sulphate and sulphuric acid, yielding uranium dissolutions of more than 95 %. Pressure leaching was tested on a laboratory scale with complete success in the 1950's[21], but was not considered for the early uranium plants because of its relatively high capital cost. In addition, it was considered essential that further pilot-scale work be done on corrosion problems to determine the most satisfactory method of transferring abrasive and corrosive pulps at high temperature and pressure, and to solve the difficulties of heat transfer.

Recently, a reassessment was made of the additional benefits that might arise from an increased recovery of gold when pressure leaching is used in a reverse-leaching situation, allowance being made for advances in the design of autoclaves and heat exchangers. The results of this study were sufficiently encouraging for a collaborative uranium-industry project to be undertaken at one of the mines, involving a demonstration plant comprising a 20 m^3 four-compartment mechanically agitated autoclave, an automatic boiler circulating steam through the autoclave and returning it via a spiral heat exchanger, and an oxygen storage and supply system. This plant is at present under construction, and testing is scheduled to start early in 1976.

8. TREATMENT OF UNCLARIFIED SOLUTIONS OR DILUTE SLURRIES BY CONTINUOUS COUNTERCURRENT ION EXCHANGE

8.1 DEVELOPMENT OF THE NIM CIX CONTACTOR

The National Institute for Metallurgy (NIM) has, for a number of years, been investigating improvements in ion-exchange engineering technology, and in particular the development of an advanced countercurrent ion-exchange (CIX) contactor for use in the hydrometallurgical processing of low-grade ores[22]. The multistage [illegible] reversal of flow for resin transfer, [illegible] was considered [illegible] suitable for further development. The NIM [illegible] now reached an advanced stage, can be summarized a[illegible]

(a) [illegible] of improved engineering components and control methods for the movement of resin into, through, and out of the extraction and elution columns;
(b) the development of standardized laboratory methods for the study of the capacity, kinetics, and hydraulic properties of resins;
(c). the application of laboratory results to process design and optimization by the use of computer methods, and to the analysis of plant per[illegible]ance data; and
(d) fundamental back-up studies [illegible]ovements to the [illegible] design and analysis.

8.2 TESTING OF THE NIM CIX CONTACTOR FOR THE RECOVERY OF URANIUM

In 1972 a pilot plant was established by the Atomic Energy Board at the uranium plant of one of the gold mines with a view to investigating the application of the NIM CIX contactor to uranium recovery. The investigation was designed to meet the following specific objectives:

(a) To demonstrate the mechanics of the system, and its reliability;
(b) to demonstrate the lower resin inventory of CIX as opposed to fixed-bed ion exchange;
(c) to test the ability of the plant to handle unclarified feed solutions;
(d) to develop a process using weak-base resin that would produce material of the same or better purity than that of a Purlex product; and
(e) to undertake a preliminary evaluation of the suitability of the system for handling uranium-bearing solutions with a solid content of up to 10 % (by mass).

This investigation has achieved all these objectives, and the results were recently published in detail[23].

8.3 RECOVERY OF URANIUM BY CIX

The successful development and application of the NIM CIX contactor to the recovery of uranium has opened up the possibility of a new generation of flowsheets for uranium recovery. The basic options in the use of the CIX technique are shown in Figure 6. The main advantage of these flowsheets over established flowsheets is a reduction in overall capital cost as a result of the elimination of the clarification step, and the replacement of the filtration step by less expensive and simpler solid-liquid separation techniques.

A comprehensive pilot-plant investigation was recently undertaken on the treatment of material from a slimes dam at one of the gold mines, by continuous countercurrent decantation (CCD), followed by CIX with strong-base resin, elution with 10 % sulphuric acid, and liquid-liquid extraction. The pilot plant was operated very successfully, and a decision has been made to go ahead with the design and construction of a full-scale plant based on this circuit, following successful demonstration trials on a full-scale CIX column at the same mine. The latter plant comprises an extraction column of 2,5 m diameter and an elution column of 1,2 m diameter, each column being approximately 10 m high.

Work is continuing on the development of alternative techniques for solid-liquid separation such as those using hydrocyclones[24], and attention is being given to the further improvement of circuits using weak-base resins.

9. IMPROVED INSTRUMENTATION FOR URANIUM PLANTS

Extensive use was made of control instrumentation in the design of South African uranium plants, particularly those constructed in 1970–1971. However, many of these instruments were supplied without adequate back-up information on their application, engineering design, installation and commissioning, and consequently they did not always perform satisfactorily.

During the past five years much progress has been made in South Africa in the development of new instruments and in the adaption of existing commercial devices for control purposes on uranium plants[25]. Thus, for example, a much-improved instrument, based on the principle of electrodeless conductivity measurement, was developed for the control of sulphuric-acid addition to the leach. At one of the plants where this instrument was subjected to full-scale trials, previous practice was for the leach operators to maintain the free acid in the leach pachucas between 2 and 10 g/ℓ by manual methods of measurement and control. The new automatic control system, using the electrodeless conductivity meter, succeeded in maintaining the free-acid level at 6,8 ± 0,4 g/ℓ, with a considerable reduction in sulphuric-acid consumption. Other developments include much-improved instruments for controlling the addition of manganese dioxide to the leach by measuring the redox potential as an indicator of the ratio of ferric to ferrous ions, and for measuring the pH in organic-continuous emulsions in Purlex plants.

All the existing uranium producers have now installed these new instruments, with considerable savings in the costs of reagents and labour, and improvements in operating efficiency.

10. CONCLUSIONS

(a) The rapid increases in the price of gold and uranium in recent years have coincided with an unprecedented increase in working costs at South African gold mines. The economic feasibility of an expansion in uranium-production capacity, particularly for the treatment of low-grade slimes dams, is strongly dependent on the development of processes that are less expensive than those employed at present.

(b) Provided that laboratory results can be reproduced on an industrial scale, wet high-intensity magnetic separation may well prove to be a major factor in the development of economic methods for the recovery of uranium from very low-grade ores and gold-plant tailings previously considered not to be worth treating for uranium.

(c) The trend in South Africa is towards higher overall extractions of gold and uranium by a changeover to reverse leaching, and by the introduction of highly intensive conditions (high concentrations of ferric ion and high temperatures) in the uranium leach.

(d) A reassessment of the economics of pressure leaching in the light of current technology and predicted economic trends, has resulted in a collaborative uranium-industry project to test this leaching on a demonstration-plant scale. The extent of the improvement achieved in the recovery of gold when pressure leaching is used in a reverse-leaching situation, will be a major factor in any decision to adopt this technique at existing or future uranium plants.

(e) The successful development and pilot-plant application of the NIM CIX contactor to the recovery of uranium has opened up the possibility of a new generation of uranium-recovery flowsheets which offer a reduction in the overall capital cost of plants by the elimination of the clarification step, and the substitution of less expensive and simpler solid-liquid separation for the filtration step.

(f) The successful development of improved instrumentation at South African uranium plants has resulted in a considerable saving in the costs of reagents and labour, and an improvement in operating efficiency.

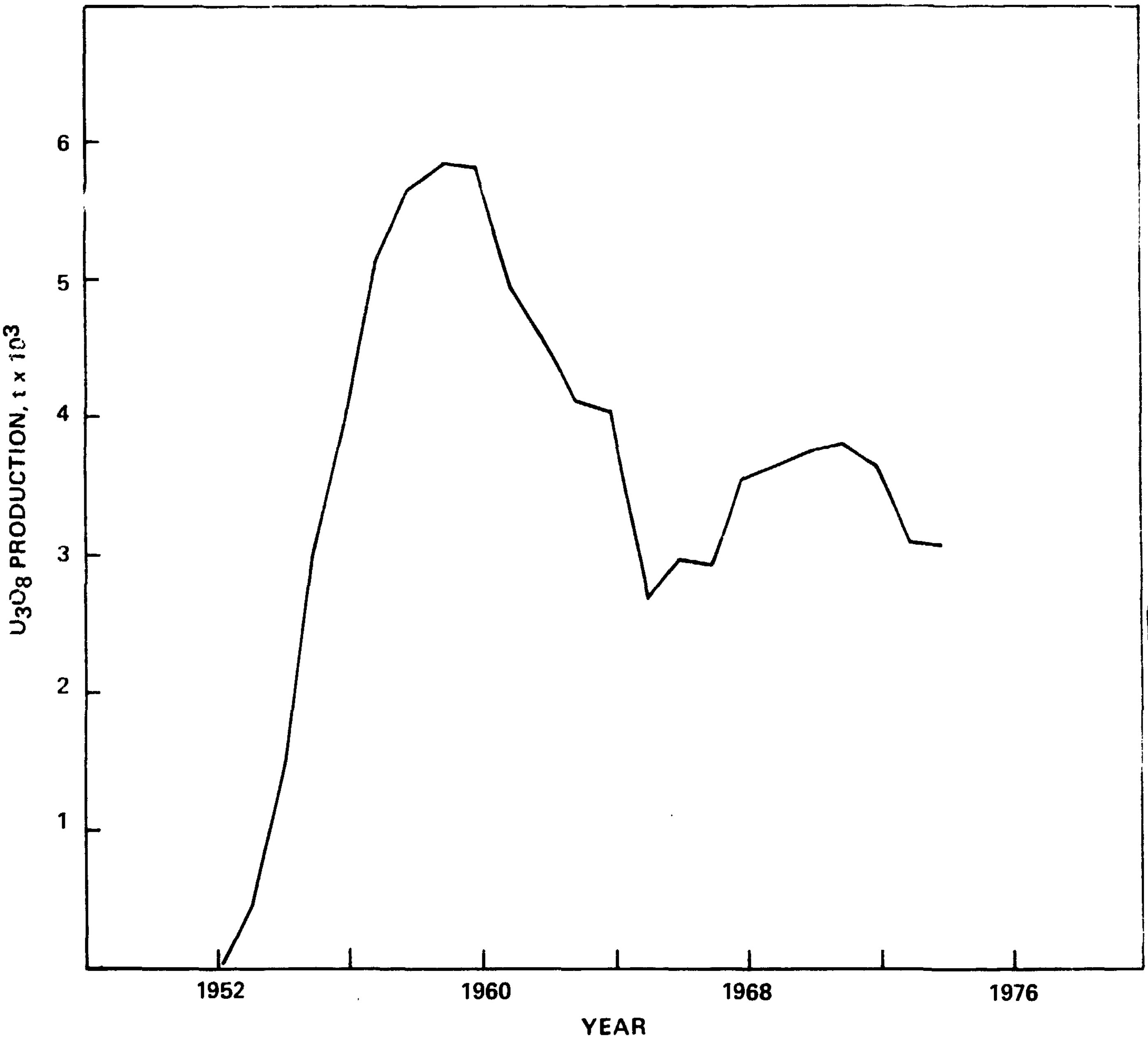

FIGURE 1
South African uranium production

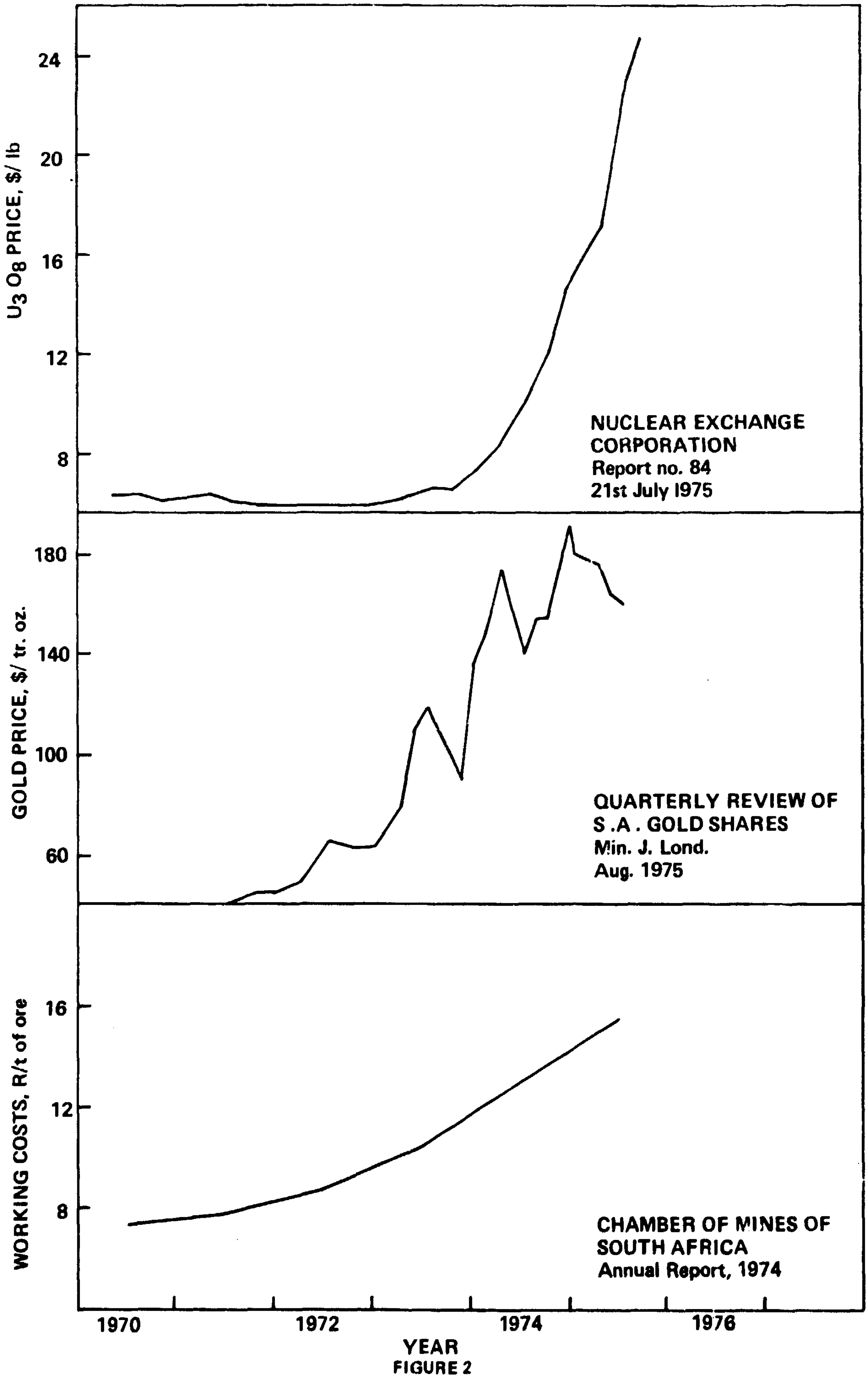

FIGURE 2

Trends in gold and uranium prices and working costs

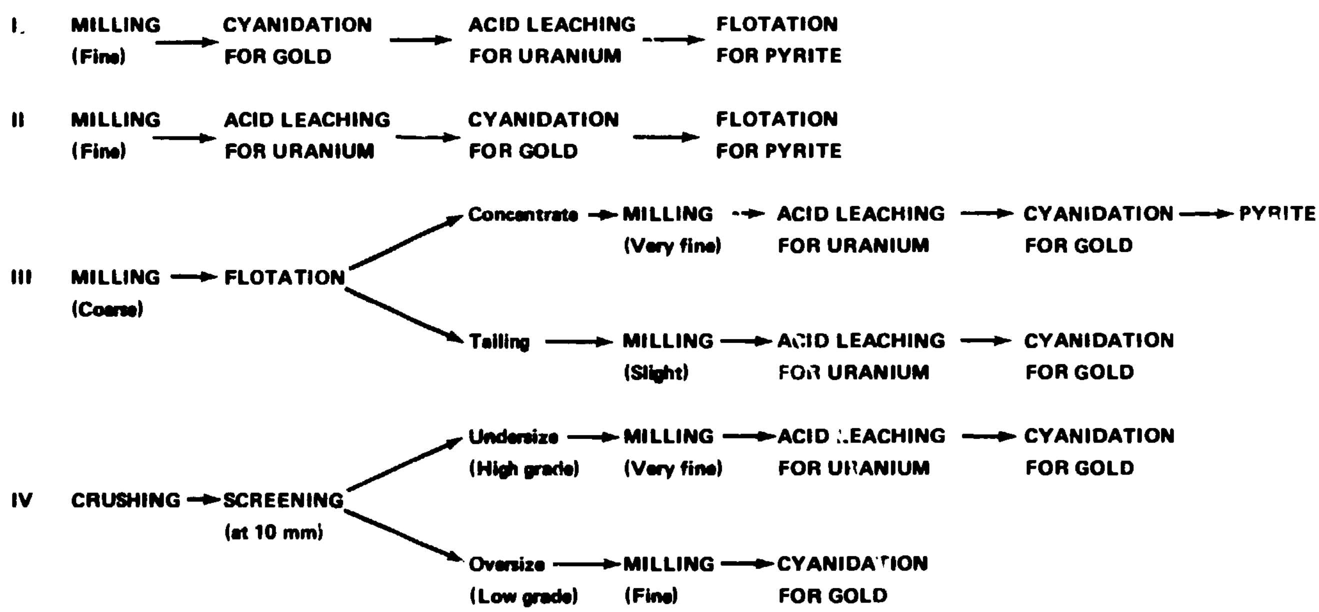

FIGURE 3

Established procedures for the recovery of uranium, gold and pyrite from Witwatersrand ores

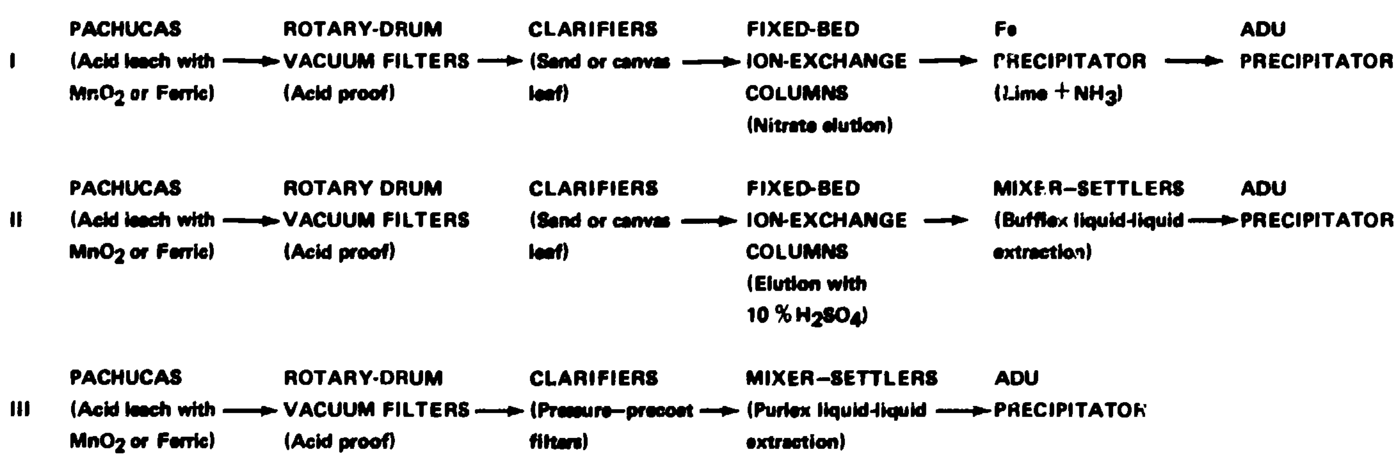

FIGURE 4

Established flowsheets for uranium plants in South Africa

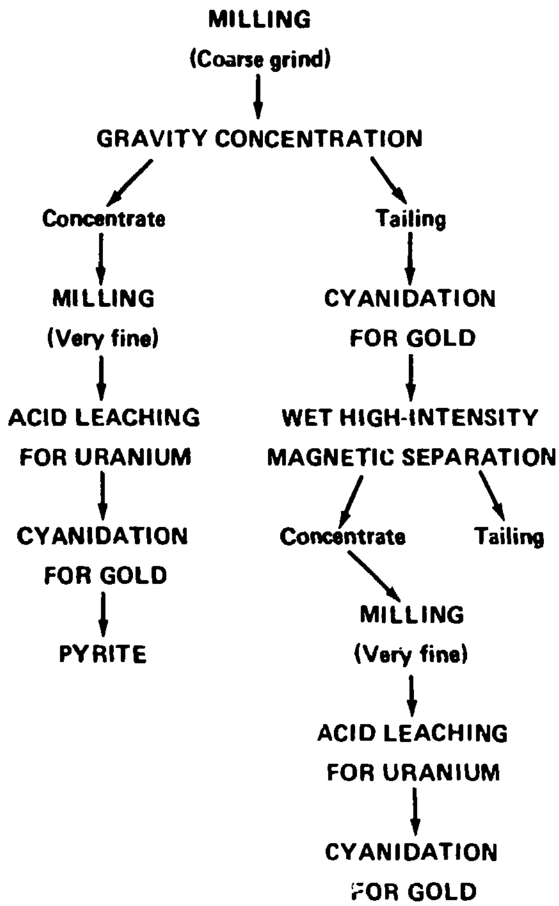

FIGURE 5
Proposed new procedure for recovery of uranium, gold and pyrite by the use of a coarse grind with gravity concentration and wet high-intensity magnetic separation

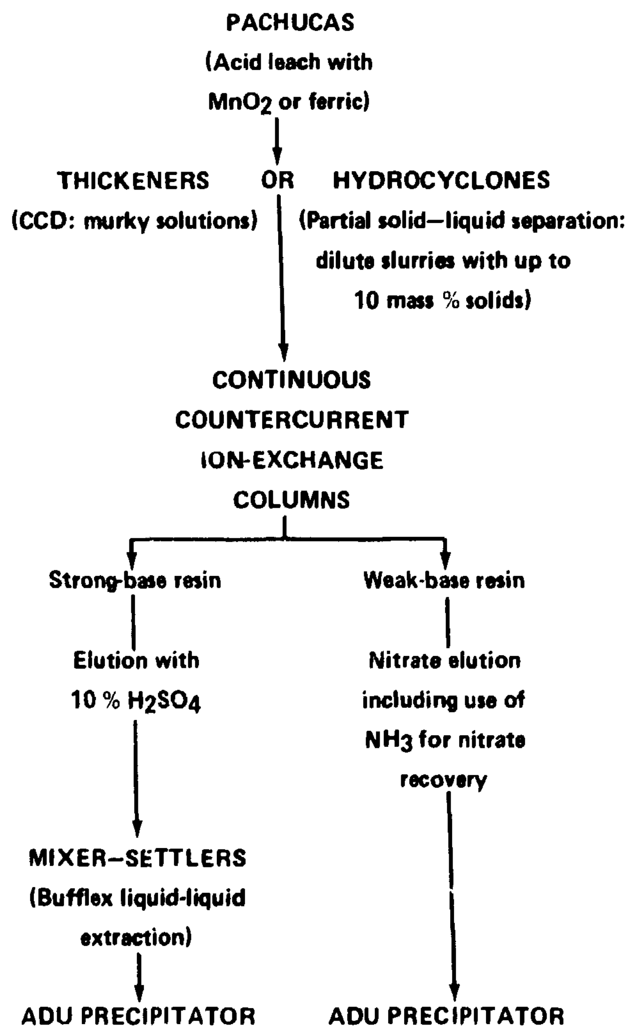

FIGURE 6
Proposed new uranium-recovery flowsheets based on the treatment of unclarified solutions or dilute slurries by CIX

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