GEOFFRY G. HUNKIN[1]

Resource Development/Utilization

Uranium In-Situ Leaching in the Tertiary Deposits of South Texas

ABSTRACT: The development of Texas uranium deposits of Eocene, Miocene and Pliocene age by *in-situ* leaching methods is in progress at six locations in Webb, Duval and George West Counties. Production trends are reviewed and show that a substantial increase in industrial activity has occurred over the past few years. Field techniques in preparing for development are discussed. The mineralogy, geochemistry, physical qualities of the host sandstones, and local ground-water conditions vary with each deposit but are generally compatible with the dissolution chemistry of alkaline-type leaching agents. A classification is discussed which relates geologic formations permeability, calcite, quartz, clays, pyrite, organic carbon and the commercial leaching processes. The environmental impact of subsurface solution mining in Bee County is explored from an industrial viewpoint.

INTRODUCTION

The modern solution-mining process for the recovery of uranium by borehole techniques is primarily a Texas development, with Colorado, Wyoming and Australia now following the Texas lead (ERDA, 1974). Each of the other uranium-producing states—Wyoming, Colorado, New Mexico, Washington and Utah have similar uraninite-coffinite sandstone deposits, but recognition of the favorable operating and capital costs of the process first occurred in Texas, and the feasibility of producing low-grade deposits was accepted. Thus, when process development had advanced to the point of commercial feasibility identified resources, sometimes with "probable ore" reserve status, had already been located by the explorationist and were available to producers.

The result is that an impressive list of producers has developed over a time span which is indeed short by mining industry standards. The present producers are indicated in Table 1. The locations of the operations are within the Texas Uranium Belt and range from Bruni, Webb County in the west to Beeville, Bee County in the east (Figure 1). Dickinson and Duval (this volume) discuss the geological aspects of many of the mines in the region. Briefly, the westernmost deposits are located in sand facies of the Catahoula Tuff; the eastern deposits lie in the basal Oakville Sandstone (Eargle and Weeks, 1973). The Palangana Salt Dome deposit of Duval County now being worked by Union Carbide is reported to be in the Goliad Formation.

[1]Consulting Engineer, Littleton, Colorado 80123.

Table I

Production Operations—Existing and Declared, 1976.

COMPANY	LOCATION	FORMATION	DEPTH (approximate)
Intercontinental Energy	Bee County	Oakville	225 ft (69m)
Intercontinental Energy	Live Oak County	Oakville	180 ft (55m)
Mobil Oil Corporation	Webb County	Catahoula	200 ft (61m)
Niagara Mohawk Uranium	Live Oak County	Oakville	450 ft (137m)
Union Carbide Corp.	Duval County	Goliad	200 ft (61m)
United States Steel	Live Oak County	Oakville	450 ft (137m)
Wyoming Minerals Corp.	Webb County	Catahoula	200 ft (61m)
Wyoming Minerals Corp.	Live Oak County	Oakville	250 ft (76m)

The attitude of the regulatory agencies of the State of Texas has been strict but generally supports the solution mining approach, in contrast to other areas where dual responsibility of state and federal agencies has been a problem to the operator. Kallus (this volume) discusses the environmental aspects of uranium mining in detail. It is likely that the long history of oil and gas exploration, particularly secondary recovery projects, provided a background of support by Texas state regulatory staff, so that process development in the field was able to progress (Hunkin, 1975).

The uranium belt labor supply has encouraged local recruiting of plant operators and the climate has permitted year-round pilot-plant development. Local support of the projects has been favorable, whereas open-pit mining has, in the past, received considerable opposition. Texas Senate Bill SB55 has added heavy land reclamation responsibilities to open-pit mining, and this has provided an additional economic incentive for the development of borehole mining techniques which leave the land surface unchanged, and frequently improved (Hirsch, this volume).

Contribution of Solution Mining to U.S. Uranium Resources. A small number of technology-conscious companies have recognized for some years the resource expansion potential of the *in-situ* solution mining approach. Such companies were active in land acquisition during the period 1971 to the present. The resource expansion is the direct result of the lower overall cost of production and thus the ability to mine lower grade or smaller ore bodies at a profit. An excellent review of solution mining costs was recently prepared by ERDA (Frank, 1976).

ERDA (1976) included for the first time solution mining reserves of at least 30 million pounds U_3O_8 (or 37.5 million tons at 0.04% U_3O_8 grade) in the $10.00 reserve classification. Reserves were distributed by mining method as follows:

Open Pit	30%
Underground Mining	35%
Solution Mining	24%
Other	12%
Total	100%

Thus, in the first year of assessment of the new solution mining process, the resource base was increased in tonnage by 24%, and all this increase was considered to be mineable at less than $10.00 per pound U_3O_8. To illustrate better the impact of these figures, the $10.00 per pound U_3O_8 figure should be compared with the present (1976) spot-price of over $40.00 per pound U_3O_8 (yellowcake product). No solution mining reserve additions were made to the $15.00 and $30.00 per pound reserve categories, but it must be assumed that these will be very large indeed.

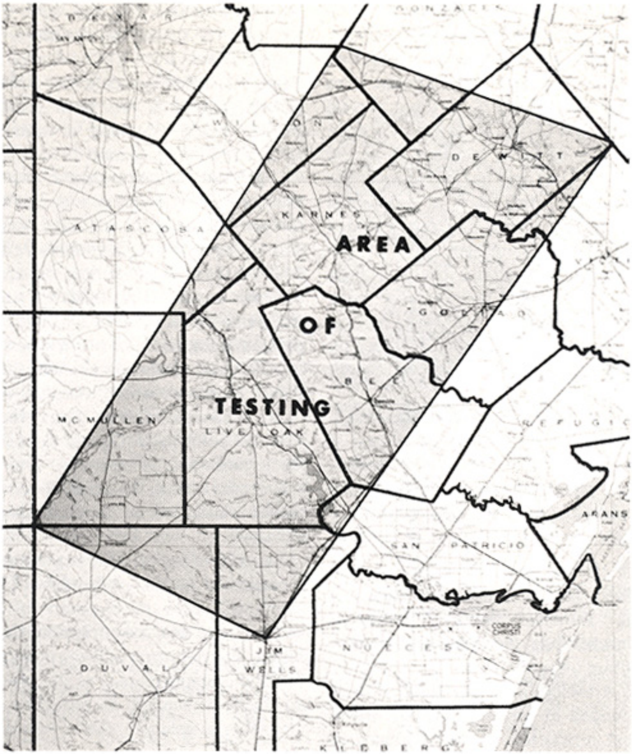

FIGURE 1. The Texas Uranium Belt—1976.

In recent years, an increasing fraction of land owners have found that open-pit mining results in an unacceptable destruction of their productive land. By contrast, subsurface solution mining is acceptable, and provides for an important expansion of the identified, available uranium resources.

Semantics of Resources and Reserves. Reserves are concentrations of a usable mineral or energy commodity which can be economically and legally extracted at the time of determination. Reserves are ready for use and can be drawn upon to meet a need (Bailly, 1976).

The term "resource," in current uranium industry and government usage, is a blanket term which describes the sum of reserves: identified sub-economic mineralization, paramarginal deposits, submarginal, hypothetical, and speculative resources. Clearly none other than "reserves" are ready for development, and of the accepted "reserve" classifications only "proven," or a balanced mixture of "proven" and "indicated" are actually ready for development, in that such deposits can attract exploitation capital (Banfield and Havard, 1975).

Thus, while resources may appear ample, ready reserves may be insufficient to fill current demand. That this latter situation exists today is indicated by the rise of uranium prices to $40 per pound from the $6 per pound of 1972-1973. In the domestic market, however, the U_3O_8 price for immediate delivery has remained fairly constant in recent months (late 1976). The rapid rise in price over the past few years has stimulated a substantial increase in the supply of uranium concentrates and has recently had a stabilizing effect on the price of uranium. The transactions that have taken place around the $40-$42/pound level have satisfied a major portion of near-term market demand; and, therefore, the upward pressure on price has been somewhat reduced, for the present (Nuexco, 1976).

Conversion of Resources and Reserves. Clearly, the problem is one of the conversion of "identified resources" into a "reserve" classification acceptable to developers and financiers (Bailly, 1976). First, let us consider those elements which fall outside the geologist's area of control:

Metal Price Increases—This index is the clearest, quickest, and most effortless means of converting the "identified resource" group to "reserves." Unfortunately, this index has a habit of reversing direction unpredictably.

Processing Technology Developments—Just as reserves are judged in terms of current metal prices, so must production costs be judged in terms of best currently available technology. Thus, an improvement in technology (which may result either in a production cost improvement, a quality improvement yielding better sales, or an increase in recovery from a given ore body) tends to improve production efficiency, and thus improve the profit margin, regardless of the state of the metal market (Hunkin, 1976). Any improvement in production cost will, over the long term, expand the resource base and, provided that there is a demand for the product, will also increase the reserves. During the past three years we have seen the effects of both of these factors, price and technology, in the Texas Uranium Belt.

Politics—As indicated by Campbell (this volume, Introduction), many tests of the political acceptability of nuclear-power generation were staged in numerous states during 1976, with the result that a clear mandate to proceed with nuclear power generation has been presented by the public. Thus the demand for uranium appears to be assured for the period 1976-1986; presumably this political hurdle clears the way for expanded nuclear generation programs and these result in further increase in demand pressures. The shortage in world fuel oil supplies and the physical limitations on western coal expansion, coupled with the increased demands for gasoline, jet fuel and petrochemical feedstocks are likely to lead to political acceptance of nuclear power generation as the most desirable electrical power source. Given such a situation, then fuel value parity, in terms of cost per kilowatt hour at the transmission line, will point to U_3O_8 per pound values about three times the 1976 prices. The expansion of resources through the ability to mine lower grade mineralization will be proportionate to this price increase.

Security of supply of energy resources imposes a constraint on the evaluation of U.S. resources which will allow development of low-grade reserves now and resources in the foreseeable future. The net result of these political pressures is that the uranium resources and reserves of Texas are being expanded, in particular, ore deposits amenable to solution mining techniques.

Pre-Mining Procedures

Conversion of resources to reserves are influenced by the form and content of geologic reports. Certain data, which may appear to have only local geological significance are often key elements in engineering and process design in solution mining. If these data are not sought and recorded in the exploration phase, then delays in exploitation will occur while another field program is mounted just to obtain this data

Continuity of reserves is essential in layout engineering for production. Vertical cross-sections which display formation data, grade of ore, oxidation state, and the geologists' interpretations of extent are the only practical way of achieving this continuity. Computer printouts are of limited value in geological interpretations.

Core samples need to be taken by specific coring and drilling-mud-control techniques that avoid contamination. These samples are required for permeability, mineralogical and metallurgical testing. The cores should be geologically described on site and immediately sealed in plastic to prevent drying and oxidation. Fresh cores should be color photographed. All boreholes must be sealed off by cementing over the entire depth. This program should commence immediately when an economic prospect has been identified; costs rise steeply when these programs have to be instituted later. All boreholes should be surveyed and located to plus-or-minus one foot; the survey should be tied to a reliable base and co-ordinates established. Ground-water levels should be carefully recorded. Mudded-up holes give unreliable results, but the driller will always know when he has intercepted the water table. Oxidation-reduction boundaries can sometimes be identified from cuttings. The well-site geologist should record these data (Campbell and Biddle, this volume).

Formation Characteristics

Identified and measured uranium resources of Texas are composed of uraninite = $(U^{4}_{1-x}, U_x^{+6})O_2^{+x}$, ideally UO_2 with minor coffinite = $U(SiO_4)_{1-x}(OH)_{4x}$ deposited at geochemical cell interfaces (roll fronts) as crystalline, anhedral solids distributed through the interstitial areas of the porous sandstones. Eargle and Weeks (1973) classified the formations into the four main groups briefly summarized in Table 2.

Associated elements of significance in processing are molybdenum, vanadium, arsenic, and selenium, which are deposited across the cell interface in a standard sequence. Identified heavy minerals are, typically:

(A) *Clastic:*	(B) *Authigenic:*
Apatite	Azurite
Biotite	Biotite
Garnet	Chlorite
Ilmenite	Goethite
Monazite	Hematite
Rutile	Malachite
Sphene	Pyrite
Tourmaline	Siderite

Porosity is typically in the 25-40% range except where post-mineralization infiltration of calcite and clays has occurred. Permeability varies widely, presumably the result of clay content and clay flocculation condition; the range of permeabilities experienced is from 150 millidarcies to 20 darcies, with a median value of about 1500 millidarcies in mineralized formations other than the Catahoula Tuff, where the median value appears to be about 450 millidarcies. Table 3 illustrates the general geologic aspects of the various South Texas uranium-producing formations and their relative amenability to subsurface solution mining.

Table 2

Classification of Geologic Environments of Uranium Ore in South Texas

1. Nearshore sandstones sandwiched between less permeable beds and overlain unconformably by tuffaceous sediments.

   Example: Jackson (Whitsett)

2. Sandstones interfingering with claystones along the side of major paleo-stream-channel deposits.

   Example: Catahoula

3. In sandstones near faults along which natural gas containing hydrogen sulfide has migrated.

   Example: Oakville

4. Sandstones above sulfurous caprock of a salt dome.

   Example: Goliad

The classic roll-front deposition pattern, as discussed by Campbell and Biddle (this volume) and by Dickinson and Duval (this volume),can not be observed directly, although the redox interface

AMENABILITY CHART FOR SOUTH TEXAS URANIUM SOLUTION MINING

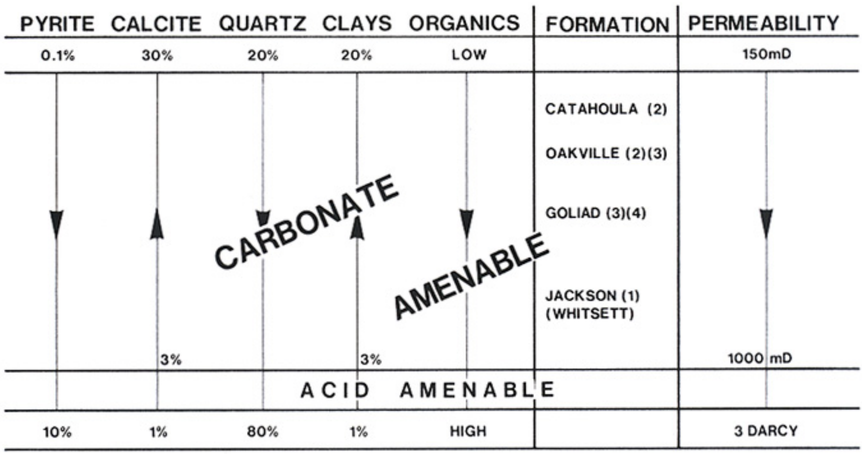

Table 3

or solution front is always apparent. Redistribution by changes in ground-water flow direction and magnitude, by fluctuations in ground-water levels, resulting in access of air, and consequent solubilization of the upper section of mineralization, and reprecipitation of uraninite in unaltered areas are commonplace and may be considered normal.

The result is a complex oxidation-reduction boundary, highly variable in geometric form in both the vertical and horizontal planes. Interpretations of mineralized zone trends without chemical analyses may be misleading (Garrels and Christ, 1965). Where uranium deposition or redistribution is geologically recent, economically significant uranium values may extend down the hydraulic gradient from the geochemical cell boundary (Harshman, 1974). Multiple, partially superimposed mineralized zones may be encountered which mimic the characteristics of upper and lower cell limbs on standard down-hole probe logs. Permeability changes and oxidation states plotted on vertical cross-sections will simplify interpretation (Honea, personal communication, 1976).

LEACHING SYSTEMS

Three approaches to subsurface solution mining have been attempted over the past ten years. Of these, ammonia systems are most applicable to the calcareous uranium ores of South Texas.

I. *ACID SYSTEMS:* generally unsuitable for Texas conditions

Oxidizer	Leaching Agent
1. $NaClO_3$	H_2SO_4
2. *Ferrobacillus thiooxidans* (maintains ferric-ferrous balance)	$Fe_2(SO_4)_3 + FeSO_4$

II. *SODIUM SYSTEMS:* direct application of conventional carbonate mill chemistry

Oxidizer	Leaching Agent
1. Air (Oxygen)	Na_2CO_3+$NaHCO_3$

III. *AMMONIA SYSTEMS:* dilute reagent systems developed specifically for *in-situ* borehole mining in Texas

Oxidizer	Leaching Agent
1. Oxygen	NH_4HCO_3+$(NH_4)_2CO_3$
2. N_2O_2	NH_4HCO_3 +$(NH_4)_2CO_3$
3. $NaClO_3$	$(NH_4)_2CO_3$
4. H_2O_2	$(NH_4)_2CO_3$

The residual effect of the leaching process is very similar to the advance of oxidizing solutions on the upstream side of a geochemical cell as indicated by Campbell and Biddle (this volume), and can be frequently identified in core specimens and sometimes in drill cuttings by the color change (Figure 2). A review of the physiochemical mechanisms involved in commercial leaching may be of value in determining some of the features of Tertiary uranium genesis:

FeS_2	$FeCO_3$	Fe_2O_3
Pyrite (Grey-Green)	Limonite Siderite (Tan)	Hematite (Brown)
Unaltered	Slightly Altered	Heavily Altered

ORE ZONE

Idealized Direction of Cell Migration

←

Basic Operating Processes. In the leaching process the uranium mineral is oxidized from the 4-valence to the 6-valence form and complexed with a carbonate to form the di- or tri-carbonate, in which condition it can be transported in aqueous solution to the production well system (Hunkin, 1975). Leach solutions are injected into the mineralized zone through injection wells in such a manner as to create an approximately horizontal flow pattern between injection and recovery wells. While in transit, contact of the reagents with the mineral surface solubilizes the uranium and sweeps away the product in solution (Figure 3).

Control of flow is achieved by the hydraulic gradient induced by the positive pressure of the injection well system. At no time is the ground-water table drawn down to such a level that the introduction of air into the ore zone of the sandstone is possible. In addition, operating well field patterns are generally simple adaptations of oil-field secondary recovery standard "five-spot" procedures, translated from the oil-field scale of five wells per section to about five wells in each two-acre plot.

The five-spot arrangement drives fluid in a rose-type pattern of flow distribution towards the center producing well (Figure 4), and is very efficient in multiple groupings, although incapable of alignment to take advantage of natural permeability or ground-water flow characteristics. Furthermore, such an arrangement is inefficient when one or two patterns are deployed over the short axis of a long and sinuous-shaped uranium deposit.

Recent developments (McKee, personal com-

Chemistry of The Ammonia Leaching System

This is a two-stage process and is expressed in its most simple form (Merritt, 1971; Butler, 1972; Hunkin, 1976).

STAGE I — OXIDATION OF URANIUM MINERALS

1. $2UO_2 + H_2O_2 = (UO_3)_2 + 2OH$

1a. $UO_2 + H_2O_2 + 2HCO_3 UO_2(CO_3)_2 = 2H_2O$

2. $U(SiO_4) + H_2O_2 + 2HCO_3 UO_2(CO_3)_2 = SiO_2 + 2H_2O$

STAGE II — COMPLEXING TO THE TRICARBONATE

3. $UO_2(CO_3)_2 + HCO_3 UO_2(CO_3)^{-4} + H^+$

The latter form is quite stable in solution.

Associated with these dissolution reactions are a series of undesirable oxidation reactions which result in pH instability and excess reagent comsumption, for example (Honea, personal communication):

1. $Fe\,S_2 = 4\frac{1}{2}H_2O_2 = Fe\,O(OH) + 2SO_4^{-2} + 4H^+ + 6H_2O$
2. $Ca\,SO_4 + 2NH_4HCO_3 = Ca\,(HCO_3)_2 + \frac{1}{2}O_2 + (NH_4)_2SO_4$

and the calcium exchange reactions:

3. $Ca^{++}\,R + 6NH_4^+ = (NH_4^+)_6R + Ca^{++}$
4. $Ra^{++}\,R + 6NH_4^+ = (NH_4^+)_6R + Ra^{++}$

munication, 1976) in computerized well layout adaptations to uranium ore bodies have demonstrated that more efficient well geometries exist for the close-spaced well systems necessary to operate within the sinuous cell fronts characteristic of Texas uranium deposits. As with all underground reservoir operations for oil, gas sulphur, potash, salt or uranium extraction, formation confinement must exist naturally or a sufficient thickness of overlying water-saturated sandstones must be present. Without this condition, the hydraulic gradients necessary for the control of fluid flows cannot be established and maintained in a stable condition.

In practice, only a few of these strata-bound deposits occur under unconfined ground-water conditions. Uranium deposits of Texas are generally understood to have been precipitated from moving ground water whose flow has been directed by the upper and lower confining shales, which serve as the confining barriers for the leaching activities (Honea, personal communication, 1976). Thus, conditions conducive to uranium genesis are parallel to the conditions for efficient mineral exploitation by *in-situ* borehole mining (Land and Archibald, 1975).

The pregnant fluids are pumped to the surface as dilute solutions of uranyl tricarbonate, concentrated by ion exchange processes, then the barren fluid is brought back to operational strength and recirculated. Early acid, sodium, and ammonia systems required heavy bleed streams to stabilize contaminated levels. Ammonium carbonate and bicarbonate systems have reduced the bleed requirements to 5-10%, and the H_2O_2 plus ammonium bicarbonate system theoretically has a zero bleed requirement. Inability to operate at or near 100% recirculation involves added costs due to:

1. Dilution of pregnant solution grade by the compensating ground-water interflow.
2. Loss of uranium and reagents in the bleed stream.
3. Cost of deep-well disposal systems.
4. Increased system water usage.

FIGURE 2. Redox Interface. The induced oxidation of chemical leaching. Dark area of core is ore material; lighter area above has been leached to remove ore.

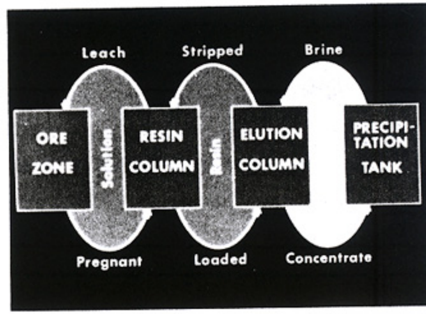

FIGURE 3. Basic circuit functions.

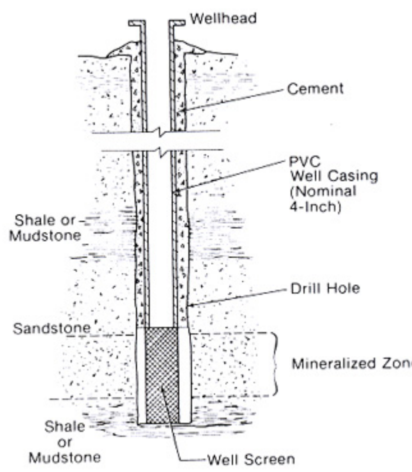

FIGURE 4. Typical borehole construction.

Tables 4 and 5 present basic cost data on production facilities in South Texas. Table 6 presents a comparison of production stages of open-pit mining, underground mining and subsurface solution mining.

Table 4
Basic Cost Data For Facilities

COST ESTIMATES		SOLUTION MINING	CONVENTIONAL MINING
Capital (1975 $)	High	$16,000,000	$70,000,000
	Low	$ 8,000,000	$40,000,000
$ Per Annual Pound Capacity	High	$8.00	$35.00
	Low	$4.00	$20.00
Overall Costs (1975 $)			
3 Mine, 1 Mill Complex		....	$11.38 lb U_3O_8
4 Solution Mining Operations		$8.93 lb U_3O_8	....
Land Reclamation Cost		....	$0.50 lb U_3O_8
Cost of First Production Shipment and Date (Assuming 15% Escalation)		$11.80 lb 1977 $	$30.64 lb 1982 $

After: Merritt, 1971; Bailly, 1976; Myers and Dale, 1966; Banfield and Havard, 1975; McKee, 1976; Hunkin, 1975.

Table 5
Costs of New Production Facilities

DATA	SOLUTION MINING	CONVENTIONAL MINING
Grade of Ore:	0.065%(1.3 lb/Ton)	0.15%(3.0 lb/Ton)
Annual Capacity:	2MM lb U_3O_8	2MM lb U_3O_8
Number of plants:	4	3 Mines 1 Mill
Lead Time to Production:		
High	3 Years	10 Years
Low	2 Years	7 Years
Date of First U_3O_8 Shipment:	1977	1982

After: Merritt, 1971; Bailly, 1976; Myers and Dale, 1966; Banfield and Havard, 1975; McKee, 1976; Hunkin, 1975.

Table 6

Comparison of Major Process Stages of Typical Uranium Mine-Mill Complexes and Solution Mining

OPEN-PIT MINES	UNDERGROUND MINES	SOLUTION MINING
Development Drilling	Development Drilling	Development Drilling
*Stripping	*Shaft Sinking	. . . .
*Mine Waste	Development Drifting	. . . .
*Waste Dump	*Waste Dump	. . . .
Develop Ore Faces	Develop Stopes	Drill Wells
*Drill, Blast	Drill, Blast	Leach Uranium
Load	Muck Out	. . . .
Haul	Haul	. . . .
. . . .	Hoist	. . . .
. . . .	Haul to Mill	Pump Solution to Mill
*Crush		
*Grind		
Leach Uranium		
Liquid-Solid Separation		
	IX or SX Concentration	
	Precipitate, Dry, Package	
*Tailings Dam Operations		Recirculate Leach Solutions
Stages To Produce Salable Product		
15 stages	17 stages	7 stages

*Indicates stages that requires extensive capital

SUMMARY OF PRODUCTION TRENDS IN THE TEXAS URANIUM BELT

The mining activity of the region is summarized below:

1965 Susquehanna Falls City mine-mill complex started.

1967 Susquehanna Ray Point mine-mill complex started.

1971 Conquista Falls City mine-mill complex started.

1972 Ray Point closed.

1972 Sabine-US Steel solution mining field test commenced.

1972 Wyoming Minerals Consortium field tests commenced (Figure 5).

1973 Susquehanna Falls City closed.

1975 Niagara Mohawk-US Steel solution mining plant started.

1976 WMC-Bruni started production (Figure 6).

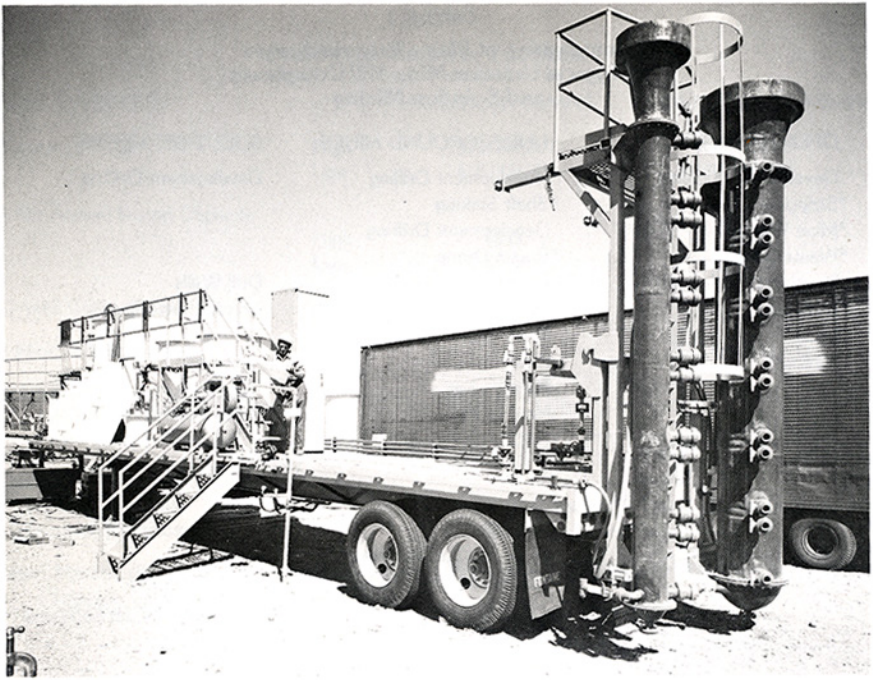

FIGURE 5. Trailer-mounted solution mining pilot plant. Part of two-unit assembly USBM Multistage I. X. Columns on right, yellow cake precipitation tanks on left.

1976 Mobil Oil Bruni solution mining plant started (Figure 7).

1976 Union Carbide Palangana solution mining plant started.

1976 US Steel solution mining plant started.

1976 IEC Pawnee plant under construction (Figure 8).

1976 WMC Lamprecht plant under construction.

Projections

1977 IEC Pawnee solution mining plant to start.

1977 WMC Lamprecht plant start scheduled.

1978 IEC-Zamzow solution mining plant start scheduled.

1978 EXXON Pama Maria mine-mill complex start scheduled.

1978 Mobil and US Steel plant-expansions scheduled.

It was observed that the producers utilizing conventional processes increased from one to three companies over an eight-year period, then dropped back to one company by 1973; this indicated a financial "shake-out." During the period 1972 to date (an overlapping period) new-

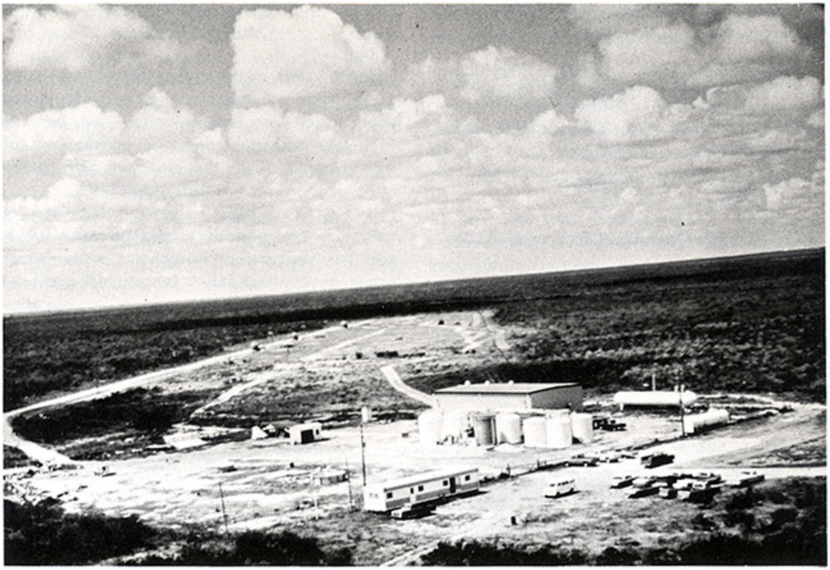

FIGURE 6. The W. M. C. Bruni concentrator.

technology plants have grown from zero to eight. While only one conventional mill is scheduled, the new-technology solution-mining growth provides an excellent example of the conversion of "resources" to "reserves" by technological advances.

IMPACT ON GROUND-WATER RESOURCES

As of 1976, the depth of solution mining of uranium ranges from 130 feet to 500 feet (40 to 153m) below surface in Texas. Future programs can be predicted to 3,000 feet (915m) and deeper. Thus, present mining activities fall within the zone of saturation, in the majority of cases under artesian conditions as a result of the confining effect of overlying shale beds.

The general ground-water movement throughout the uranium belt is eastward or southeastward toward the Gulf Coast (Meyers and Dale, 1966). Reversals occur locally as a result of local drainage patterns, and such events can generally be forecast from examinations of stream patterns and drainage divides.

Ground-water velocities have been estimated to be in the order of 10 feet (3m) per year and this is likely to be the maximum. For example, the volume in transient storage in the Bee County section of the Gulf Coast aquifers is estimated at 48 million acre-feet (Meyers and Dale, 1966) from which a perennial yield of 9,000 acre-feet, or 8 mgd can be exploited without deleterious long-term effects. A similar volume of annual recharge adds 8 million gallons per day (mgd) for a total of 16 mgd available for development; usage is 5.6 mgd (1966).

Taking Bee County as representative of the Coastal Plain counties of the Texas Uranium Belt, the developing water usage from future uranium solution mining projects gives the following figures:

Estimated Bee County Uranium Production:
5×10^6 pounds U_3O_8/yr (over 10 yrs)

Water Usage (per pound U_3O_8), Maximum:
60 gallons

Daily Usage, Uranium Recovery:
0.082 mgd

Daily Usage, Agricultural, Industrial, Municipal:
5.6 mgd

Maximum % Predicted for Full Uranium Production/Development
as % of use: 1.46%
as % of available: 0.51%

It is clear, therefore, that a fully developed solution-mining industry will not place a significant demand on Bee County ground-water resources.

Ground-Water Quality Changes

There is little evidence that the solution mining of uranium will have any measurable impact outside extremely localized areas of the order of 100 acres, and such effects will be transient and small compared with the impact of such natural atmospheric events as hurricane Hazel.

It seems reasonable to assume that the large quantities of meteoric water charged with carbonic acid delivered by a wet hurricane, an event which occurs several times each century, will leach out salts and fertilizer materials in its migration downwards towards the ground-water table and result in an overall total dissolved solids (TDS) content increase in the ground water significantly greater than the contribution of the controlled, localized solution mining projects.

Recent process developments are, in any event,

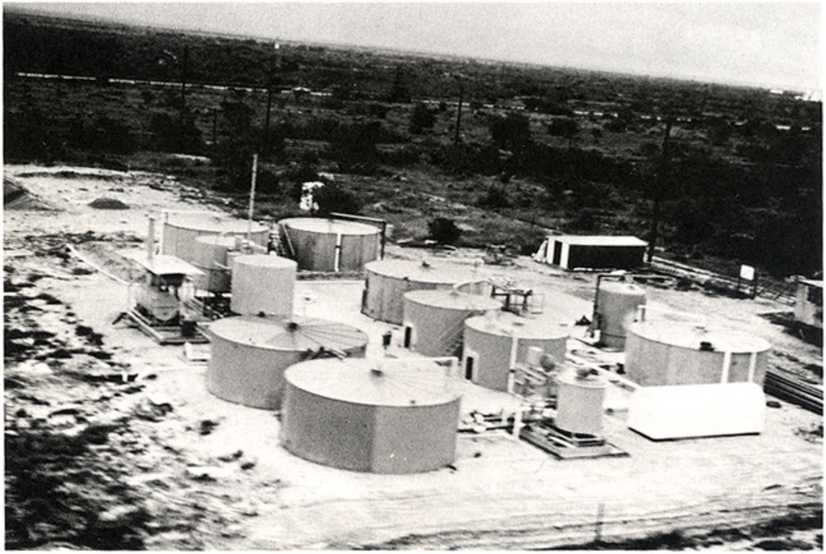

FIGURE 7. Mobil O'Hern pilot plant.

more environmentally acceptable than the early processes and have eliminated the chloride buildup resulting from the use of NaCl or NH Cl as the ion exchange eluant. Reduction of chloride buildup contributes to lower sulfate buildup and thus reduces solubilization of calcium. The net result is a reduction in the operational fluid bleed stream requirements and, thus, a potential 10% reduction in water usage.

It must be remembered that the area of land and the volume of formation under treatment for uranium recovery, both in the aggregate and at any one time, is very small. The higher TDS values generated by the oxidation activities of uranium leaching will be rapidly buffered and diluted so as to become indistinguishable from representative ground-water quality of the naturally mineralized formation (Kallus, this volume).

Regulatory Agencies and Operating Licenses

The State of Texas administers the primary environmental control of ground-water quality and surface discharge through the Texas Water Quality Board. Radiation exposure to personnel, and redistribution of radiation emitters in the vicinity of the ore deposit, is controlled by the Texas Department of Health, Division of Occupational Health and Radiation Control. Licensing procedures require comprehensive technical descriptions of extraction and recovery processes, well field operations, monitoring installations and rehabilitation programs. The mining activities are governed by the Mine Enforcement and Safety Administration (MESA), a federal agency. Kallus (this volume) explores the position of the U. S.

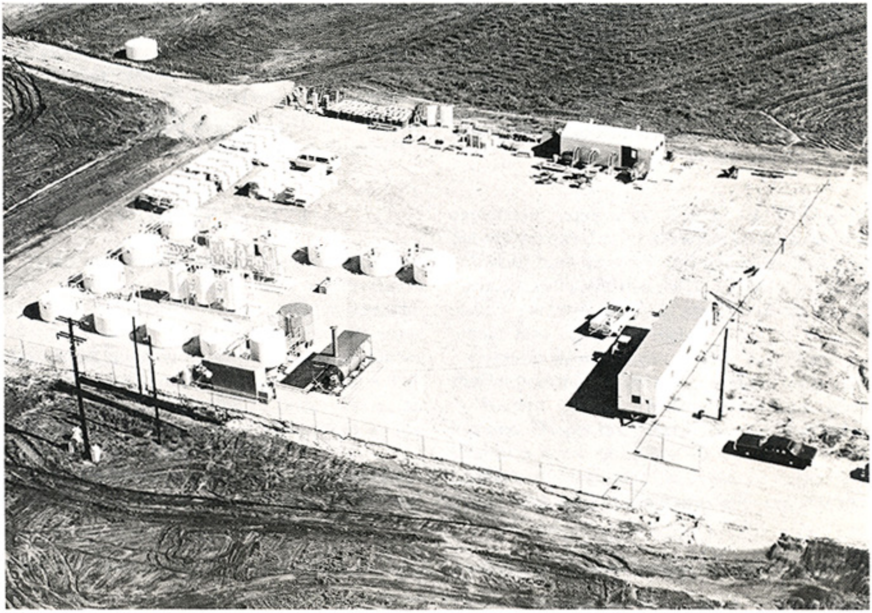

FIGURE 8. Intercontinental Energy Corp. Pawnee uranium concentrator.

Environmental Protection Agency with regard to uranium mining in Texas. Additional references to subsurface mining technology and related aspects may be found in Chapter 5 Selected Uranium Bibliography.

REFERENCES

Bailly, P. A., 1976, The problems of converting resources to reserves: Mining Eng., vol. 27, no. 1, January, pp. 27-37.

Banfield, A. F., and J. F. Havard, 1975, Let's define our terms in mineral evaluation: Mining Eng., vol. 27, no.7, July, pp. 74-78.

Butler, R. D., 1972, Carbonate leaching of uranium ores—a review: presented at the Aust. Atomic Energy Commission Symp. of Uranium Processing (Lucas Heights—July 20-21, 1972), 14pp.

Eargle, D. H., and A. D. Weeks, 1973, Geologic relations among uranium deposits, Coastal Plain Region, USA, *in* Amstutz, G. C. and A. J. Bernard (eds.) Ores in Sediments: Springer-Verlag, New York, pp. 101-113.

ERDA, 1974, Bibliography of uranium leaching: ERDA Rpt. GJO-107 (74), November, 8 pp.

ERDA, 1976, Statistical data of the uranium: ERDA Rpt. GJO-100 (76), pp. 44.

Frank, J. N., 1976, Cost model for solution mining of uranium: ERDA Rept. GJO-108(76), pp. 201-225.

Garrels, R. M., and C. L. Christ, 1965, Solutions, minerals and equilibria: Freeman Cooper & Co., 325pp.

Harshman, E. N., 1974, Distribution of elements of some roll-type uranium deposits: I. A. E. A. Sym. Form. Uranium Ore Deposits (Athens, Greece—May 6-10/73), IAEA-AM-183/4, pp. 169-183.

Hunkin, G. G., 1975, The environmental impact of solution mining for uranium: Journ. Amer. Mining Cong., vol. 61, no. 10, October, pp. 24-27.

Hunkin, G. G., 1976, Concentration processes for uranium *in-situ* leach liquors: Ann. Mtg. Soc. of Mining Eng. of AIME, 21 pp.

Lang, E. A., and W. R. Archibald, 1975, Innovative systems for the recovery of uranium: Colorado Mining Assoc. Yearbook, pp. 114-118.

Merritt, R. C., 1971, The Extractive Metallurgy of Uranium: Colorado School of Mines Research Institute, 72 pp.

Myers, B. N., and O. C. Dale, 1966, Ground-water recoveries of Bee County, Texas: Texas Water Development Board Rpt. 17, 68 pp.

Nuexco, 1976, Uranium oxide process—1968 to 1976: Nuclear Exchange Corporation Fall Report, 27 pp.