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Volume I

ENGINEERING ASSESSMENT AND FEASIBILITY STUDY OF CHATTANOOGA SHALE AS A FUTURE SOURCE OF URANIUM

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JUNE 1978

Prepared for **THE U.S. DEPARTMENT OF ENERGY GRAND JUNCTION OFFICE**

ENGINEERING ASSESSMENT AND FEASIBILITY STUDY OF CHATTANOOGA SHALE AS A FUTURE SOURCE OF URANIUM

Prepared For

BENDIX FIELD ENGINEERING CORPORATION
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Commissioned By

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VOLUME I

ECONOMICS AND FEASIBILITY OF EXPLOITATION OF CHATTANOOGA SHALE FOR URANIUM AND BY-PRODUCTS

ABSTRACT

As the first two parts of a four-part study sponsored by the U.S. Department of Energy, this report describes the engineering, feasibility, economics, and environmental aspects of exploitation of Chattanooga Shale to recover uranium, synthetic crude oil, and by-product thorium, ammonia, sulfur, molybdenum, vanadium, nickel, and cobalt. The encouraging conclusions indicate that the Chattanooga Shale is technically, economically, and environmentally a potential source of uranium, energy, and by-product metals, assuming successful future research and development (particularly hydroretorting) and favorable by-product metals market impact.

Shale stratigraphy and critical feasibility considerations are addressed. Geology of the Chattanooga Shale and adjacent strata is reviewed. Calculated shale reserves in Gassaway plus Maury formations in DeKalb County, Tennessee are 595 million short tons of 55 ppm U and inferred reserves are more than 8,000 million tons. Additional reserves in other areas are listed.

A room and pillar mining system operating in three nearly identical underground mines is designed to provide 100,000 short tons of ore to the processing plant each day. Mine capital is estimated at $56 million, mining costs at $2.34 per ton, and backfilling at $0.48 per ton. Land acquisition and royalties are estimated at $2.00 per ton.

Shale treatment comprises crushing, drying, hydroretorting, and refining to make synthetic crude oil, sulfur, and ammonia. Retorted shale is further roasted and leached with acid, and the resulting solutions are processed to recover uranium, thorium, molybdenum, vanadium, nickel, and cobalt. Heat surplus to the process is recovered as electrical energy. About 70 percent of the leached tailings is returned to the mines for fill after cycloning for slime removal. Provisions must be made for

competent surface tailings storage areas for the remaining 30 percent (24,000 dry tons per day). Capital cost estimate for the entire plant including mine and backfill is $2,303 million.

Economic evaluation of the process is based upon treatment of 100,000 short tons per day of Chattanooga Shale to make an estimated 49,900 barrels of synthetic crude oil, 6,700 pounds of uranium as yellow cake, 490 tons of NH_3, and 1,600 long tons of sulfur. Also an estimated potential annual production of 12,280,000 pounds of vanadium, 8,050,000 pounds of cobalt, 18,550,000 pounds of nickel, 7,000,000 pounds of molybdenum, 350,000 pounds of thorium, and 162,000 KWH continuous power is possible, contingent upon satisfactory markets. For the case in which the shale contains 55 ppm U and all by-products are made and sold, a direct annual operating cost of $416 million, 8.9 percent return on investment, and 8.1 years payout are estimated at $50.12 per pound of U and $14 per barrel of syncrude prices. Other cases are also presented.

The hydrocarbon yield from a ton of Chattanooga Shale is shown to equal 0.55 barrels of high quality syncrude per ton of shale; not insignificant in view of current large imports of uncertain foreign oil. The syncrude produced is a sulfur-free, low-nitrogen, 30° API oil with over 75 percent yield in the diesel-fuel or jet-fuel boiling range. As such, it may be worth more than the estimated $18.30 per barrel selling price.

The net energy yield, expressed as KWH of electrical energy, from the uranium, thorium, and other sources recoverable from Chattanooga Shale was examined. In the LWR (light water reactor) with plutonium recycle and utilizing additional thermal energy in the shale, the net yield per ton is comparable to bituminous coal. Using the breeder reactor cycle plus the thermal energy, the total net energy in a ton of Chattanooga Shale is 94 times as great as that contained in a ton of bituminous coal.

The environmental impact of the Chattanooga Shale operation is assessed in a general fashion, inasmuch as a specific plant site area has not been selected. Some environmental costs, such as tailings dam construction, tailings water treatment and reclamation, and mine backfilling are represented in the cash flow analysis. Socioeconomic costs were not included, since the analysis was not performed on a site specific basis.

The environment of the Chattanooga Shale region is described in terms of physiography and geomorphology, climatology and meteorology, air and water resources, biological resources, and cultural resources. Conceptual or "model" conditions are established for the purposes of impact analysis. The preliminary analysis indicates that, in general, a massive recovery project on the Chattanooga Shale could be environmentally accommodated in the event of proper site selection and careful planning.

The principal potential impacts associated with the contemplated project relate to the generation and management of process wastes, and to the alteration of the existing socioeconomic structure of the project environs. Process wastes are seen as a matter of concern both from the standpoint of their possible entry into the natural hydrologic environment, and due to the extensive land area required for tailings storage. Potential impacts to the social and economic character of the affected area are projected as a mix of both adverse and beneficial. Major changes are anticipated in employment, population size, income, tax base, land use, and quality of life.

The potential constraining influence of environmental regulations upon the project is considered through the identification and discussion at the Federal and state level of regulatory agencies, existing and anticipated legislation, and required permits that would impinge upon the establishment and operation of a large-scale uranium recovery facility within the region in question.

The study of the processing of Chattanooga Shale was facilitated by a comprehensive, annotated bibliography, which is included in the report. A review of a comparable shale operation at Ranstad, Sweden, was particularly helpful.

FOREWORD

The U.S. Department of Energy has an ongoing interest in all aspects of energy: its uses, sources, costs, and availability. Continuing depletion of higher grade U.S. reserves of uranium to supply escalating energy requirements has provided the motivation to examine more closely other possible sources of uranium. One of these is the long-known Chattanooga Shale resource of large tonnage but low grade in the east-central United States.

This investigation, executed to determine the technical, economic, and environmental feasibility of large-scale production of uranium from Chattanooga Shale, was commissioned to the subcontractor, Mountain States Mineral Enterprises, Inc., through the primary contractor, Bendix Field Engineering Corporation, for the Department of Energy. It represents the first two phases of a contemplated four-phase program.

The report consists of three volumes. The first, prepared by Mountain States Research and Development, a division of Mountain States Mineral Enterprises Inc., covers the engineering description, feasibility, and economics of exploitation of the Chattanooga Shale. Cleveland-Cliffs Iron Company, Western Division was commissioned by Mountain States to prepare the portion on underground mining and tailings backfill. Information for portions of the first volume dealing with oil retort processing from shale was furnished by the Institute of Gas Technology, Chicago. The second volume is devoted to the environmental and socioeconomic impacts of exploiting the Chattanooga Shale and was provided by Toups Corporation of Orange, California as a subcontractor to Mountain States. The third volume contains appendices including the complete underground mining report. Annotated bibliographies consisting of cited references and other relevant literature are included in Volumes I and II.

Portions pertaining to Ranstad, Sweden were written by the principals of this report from published references, personal communications, and observations made by representatives of Mountain States and Toups on a visit to the Ranstad operation in November, 1977.

This study accomplishes the data compilation and analysis phase (Phase I) and feasibility report phase (Phase II) of a program to determine the viability of Chattanooga Shale as a future source of uranium.

Phase I requires the compilation and analysis of all available technical and environmental information pertinent to a study and evaluation of the feasibility of exploiting the Chattanooga or similar shales for uranium and possible by-products. Information gathered includes that relating to geology, resource estimation, mining methods, and processing in addition to the geography, demography, and environmental characteristics of the Chattanooga Shale region.

This information, together with that gained from a review of the Swedish Ranstad operation, is applied to a review and evaluation of current assessment, exploitation, and extraction technology applicable to, and impacts to be expected from, the large-scale production of uranium from Chattanooga Shale. Environmental and socioeconomic impediments to such an operation are delineated from an examination of current and anticipated regulatory, environmental, economic, and social aspects of exploitation.

Phase II requires the preparation of comprehensive reports presenting the results of investigations carried out in Phase I. One portion of this report is devoted to the economics and feasibility of recovering uranium and by-products from Chattanooga Shale based on current technology. A separate portion discusses the assessment and evaluation of the regulatory, environmental, and socioeconomic impacts resulting from large-scale exploitation of the Chattanooga Shale as a uranium source.

The report includes comprehensive annotated bibliographies concerning geologic studies, mining practices, processing, environmental impact and other information based upon relevant studies carried out by government agencies, universities, and private companies both in the U.S. and foreign countries (e.g., Sweden's Ranstad project). An annotated bibliography with references applying to geologic, mining, and processing aspects is included in Volume I and a similar bibliography of references relating to environmental and socioeconomic considerations is included in Volume II.

Since most previous reports including the Ranstad papers dealt in U, and not U_3O_8, this report deals in U (uranium metal) except where noted in parenthesis. The conversion factor from percent uranium (U) to uranium oxide (U_3O_8) is division of the uranium (U) assay by 0.848.

The question of economic feasibility addressed by this report is a complex problem influenced by many factors, some readily quantifiable, others impossible at this juncture to remove from the realm of the subjective. If the technologies of exploitation projected in this report are valid and the growth in world energy consumption persists, the economic feasibility of the resource may be closer in time than many observers would expect. Given today's selling prices for oil of $14 per barrel and $42.50 per pound of U_3O_8 ($50 per pound of U), the value of one ton of shale is about $10.55. The uranium value is $3.30 in a ton of shale "as-mined" at an average grade of 55 ppm U and 60 percent processing recovery. Included also in this value in a ton of shale is $7.25 for the oil recovered by a new process, hydroretorting, to yield 21.7 gallons per ton rather than the indicated Fischer assay content of 8.7 gallons per ton. Above this, the process produces all the sulfur required for leaching uranium, and a small amount of ammonia for sale.

The environmental and socioeconomic effects, however, will be great because of the scale of disturbance necessarily associated with mining and processing the large shale tonnages required for the resource to be of any real significance in uranium supply. These effects could be of such importance as to require perhaps a new concept of ownership, development, and use.

Presented in this report are descriptions of techniques for mining and processing appraised as being feasible now or in the near future after a period of trial and testing. The success of such technical innovation and development, along with the important influencing factors of world politics and economics, will determine the timing of initial production.

CONTENTS

VOLUME I

CONTENTS (Continued)

CONTENTS (Continued)

CONTENTS (Continued)

CONTENTS (Continued)

CONTENTS (Continued)

Page

VOLUME III

LIST OF TABLES

LIST OF TABLES (Continued)

LIST OF TABLES (Continued)

LIST OF FIGURES

LIST OF FIGURES (Continued)

LIST OF FIGURES (Continued)

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Appreciation is expressed to the Technical Library of the University of Arizona, the Norlin Library of the University of Colorado, the Grand Junction Library of the Department of Energy, and the library of the U.S. Bureau of Mines at Pittsburgh for help in finding references.

Special recognition is due earlier writers on the Chattanooga Shale resource: T.M. Kehn, R.C. Hickman, and particularly P.H. Mutschler and his collaborators who coordinated, codified, and tabulated all the previous shale sample measurements, locations, and analyses.

Appreciation is expressed to several industrial enterprises which furnished for observation recent diamond drill cores of the Fort Payne, Maury, Chattanooga, and Leipers formations.

REPORT DEVELOPMENT PERSONNEL

Principal members of the research team responsible for this report are listed below.

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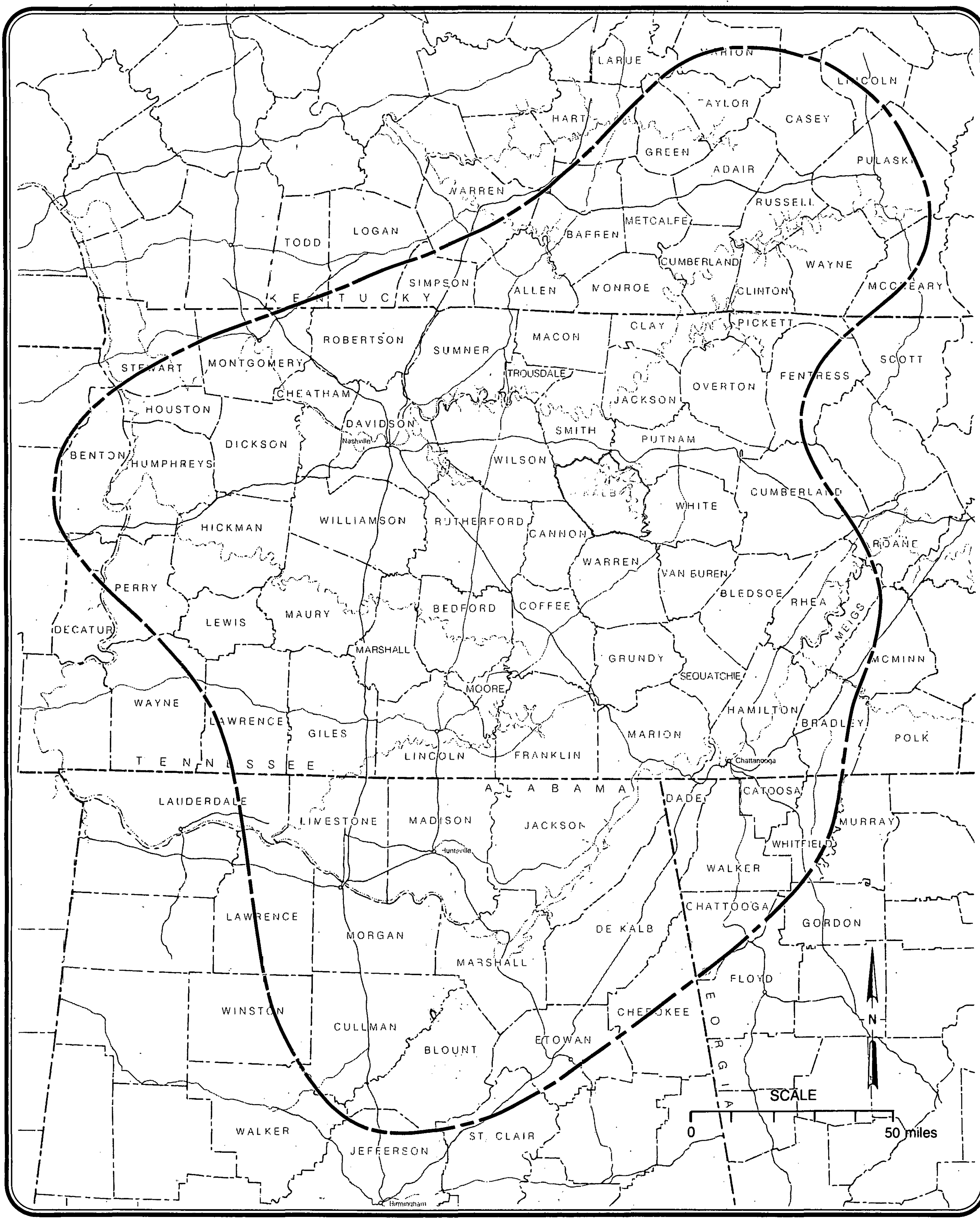
SECTION I
INTRODUCTION AND SUMMARY

Interest in the Chattanooga Shale as a source of uranium was generated as early as 1944 because of the knowledge that black marine shales oftentimes are uraniferous. Reconnaissance surveys and investigations conducted for the U.S. Atomic Energy Commission (AEC) by the U.S. Geological Survey (USGS) and the University of Tennessee were carried out over an area of about 35,000 square miles of Tennessee, Kentucky, Alabama, and Georgia [Stockdale and Klepser 1959]. This area (Figure I-1) represents the regional study area addressed by this report. Except for a few scattered boreholes, most of the information about the Chattanooga Shale and its characteristics was based upon examination of outcrops. Early investigators covered large areas and took many samples from the numerous outcrops of the shale [Brill and Nelson 1944; Glover 1959; Stockdale and Klepser 1959].

In 1952, the U.S. Bureau of Mines (USBM) embarked upon an exploratory program consisting ultimately of 64 holes drilled over an area situated mostly in Tennessee along the Northern and Eastern Highland Rim and in several counties of the Cumberland Plateau, including the Sequatchie anticline, further east, and stretching as far south as Blount County, Alabama (Figures I-2 and I-3) [Stockdale and Klepser 1959; Kehn 1955]. Broadly summarized, to date this exploration program has disclosed Chattanooga Shale occurrence in large areas of Tennessee, Kentucky, Alabama, and a small portion of northwest Georgia (Figure I-4).

Mineral interest in the shale is presently focused in the Northern and Eastern Highland Rim area of Tennessee comprising 12 counties (Figure I-5). The Rim area cut by stream valleys forms a 300 to 500 foot escarpment surrounding the eroded lower Nashville Basin (Figure I-4). The Chattanooga Shale is exposed in many places in the higher northern and eastern parts of the escarpment [Hickman and Lynch 1967]. The data accumulated

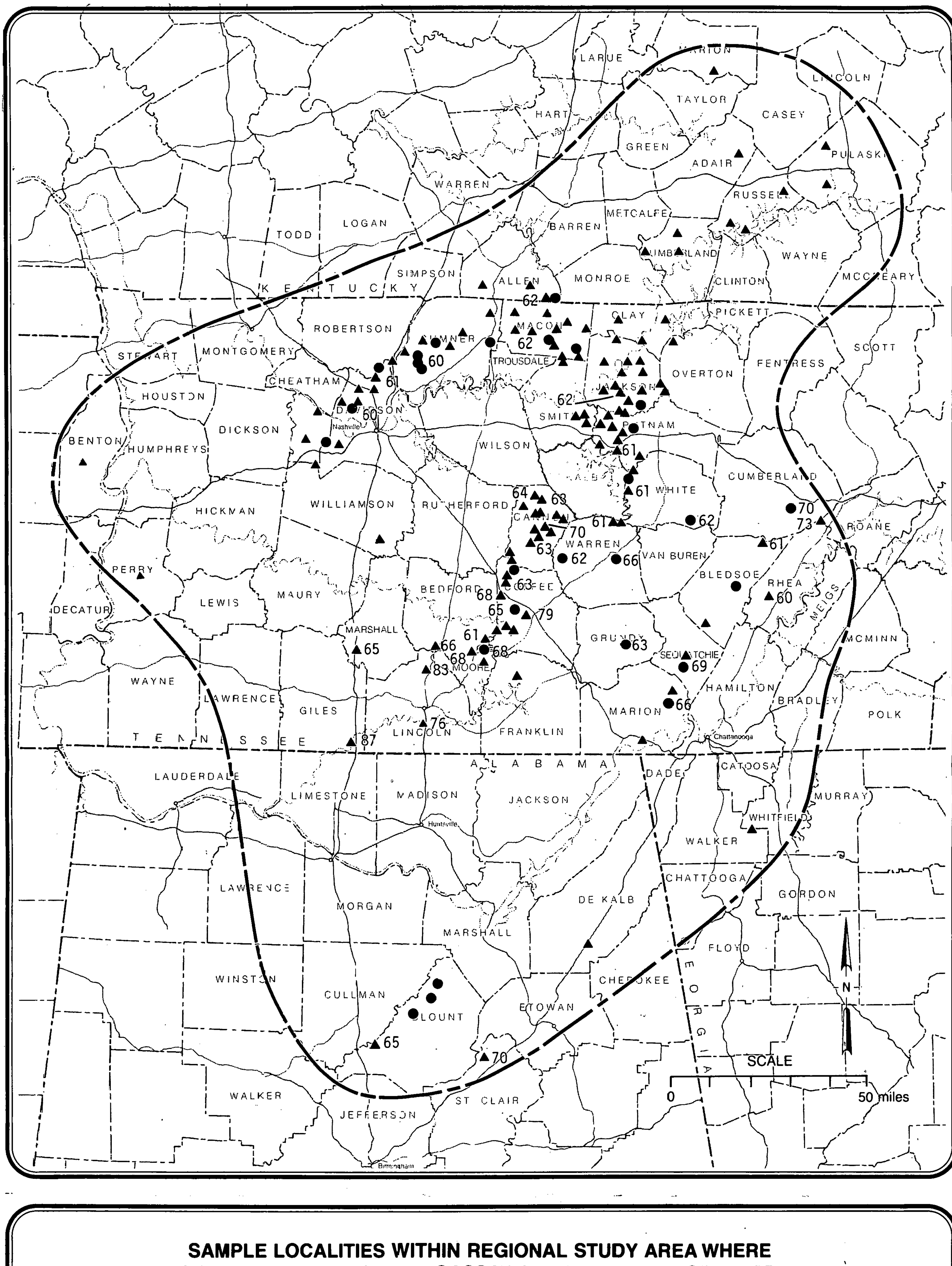


REGIONAL STUDY AREA

KEY

— — — Study Area Border

FIGURE I-1

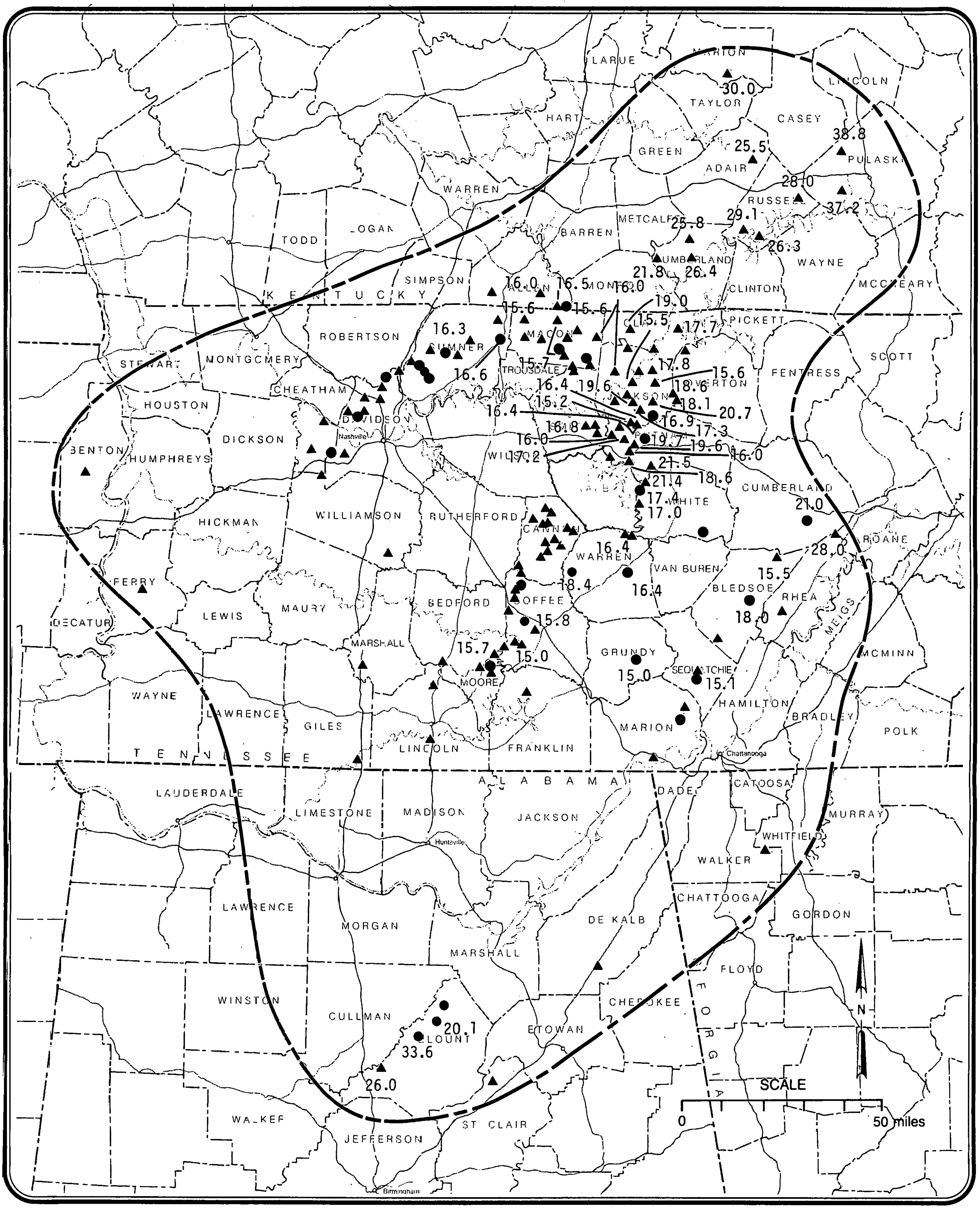


SAMPLE LOCALITIES WITHIN REGIONAL STUDY AREA WHERE URANIUM VALUES OF THE GASSAWAY MEMBER ARE GREATER THAN 60 PPM (0.0060 PERCENT)
(adapted from Mutschler, et al. [1976])

KEY

● Drill Hole
▲ Outcrop
66 Uranium assay (ppm), weighted average. 66 ppm = 0.0066%

FIGURE I-2



SAMPLE LOCALITIES WITHIN REGIONAL STUDY AREA WHERE THICKNESSES OF THE GASSAWAY MEMBER ARE GREATER THAN 15 FEET (adapted from Mutschler, et al. [1976])

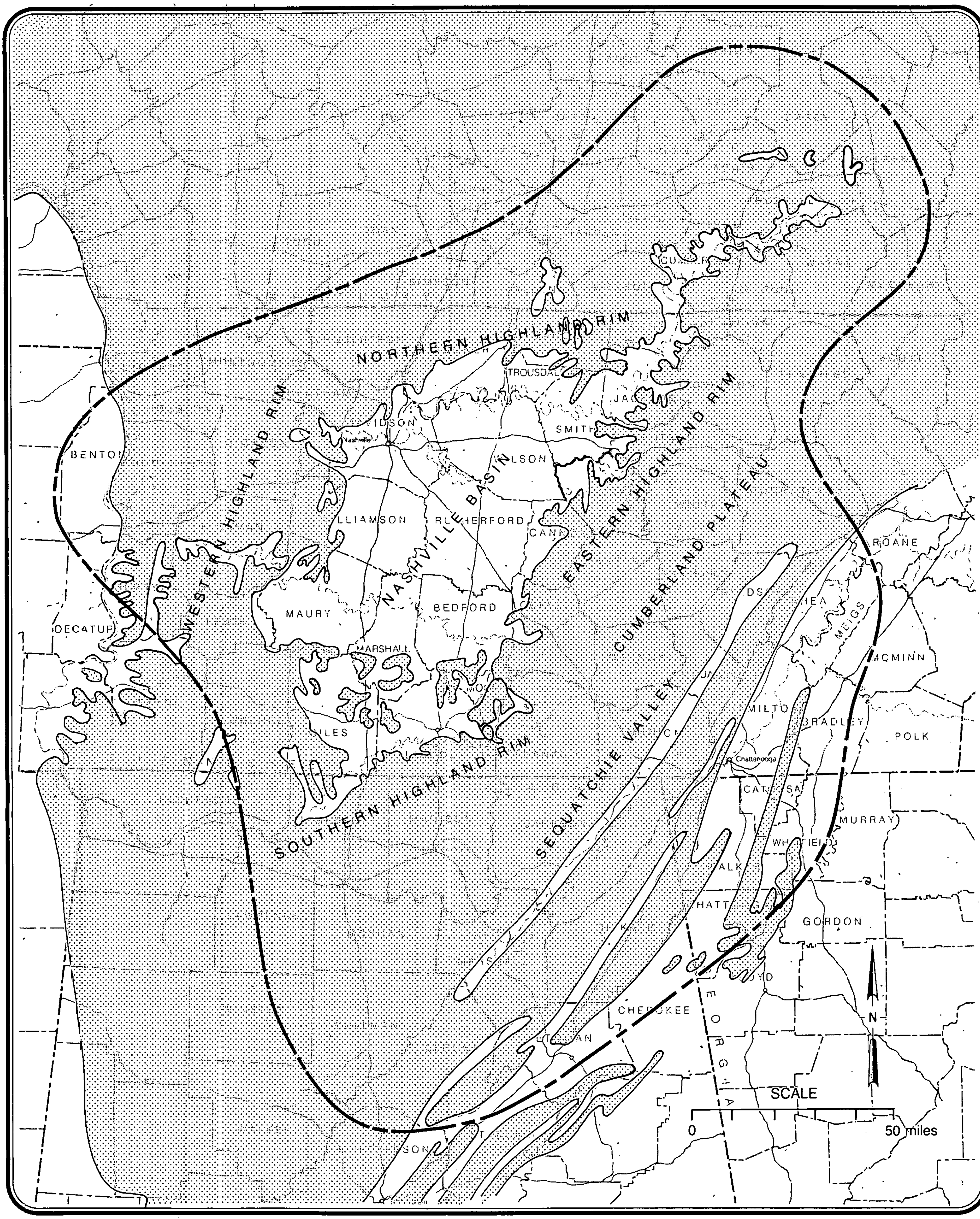
KEY

● Drill Hole

▲ Outcrop

15.0 Thickness of Gassaway Member (feet)

FIGURE I-3



AREAL EXTENT OF THE CHATTANOOGA SHALE IN TENNESSEE AND ADJACENT AREAS
(adapted from Mutschler, et al. [1976])

KEY

- Area in which Chattanooga Shale is generally present
- Area in which Chattanooga Shale is generally absent

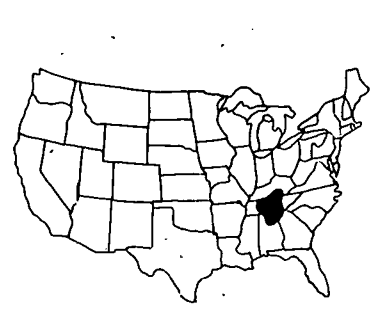
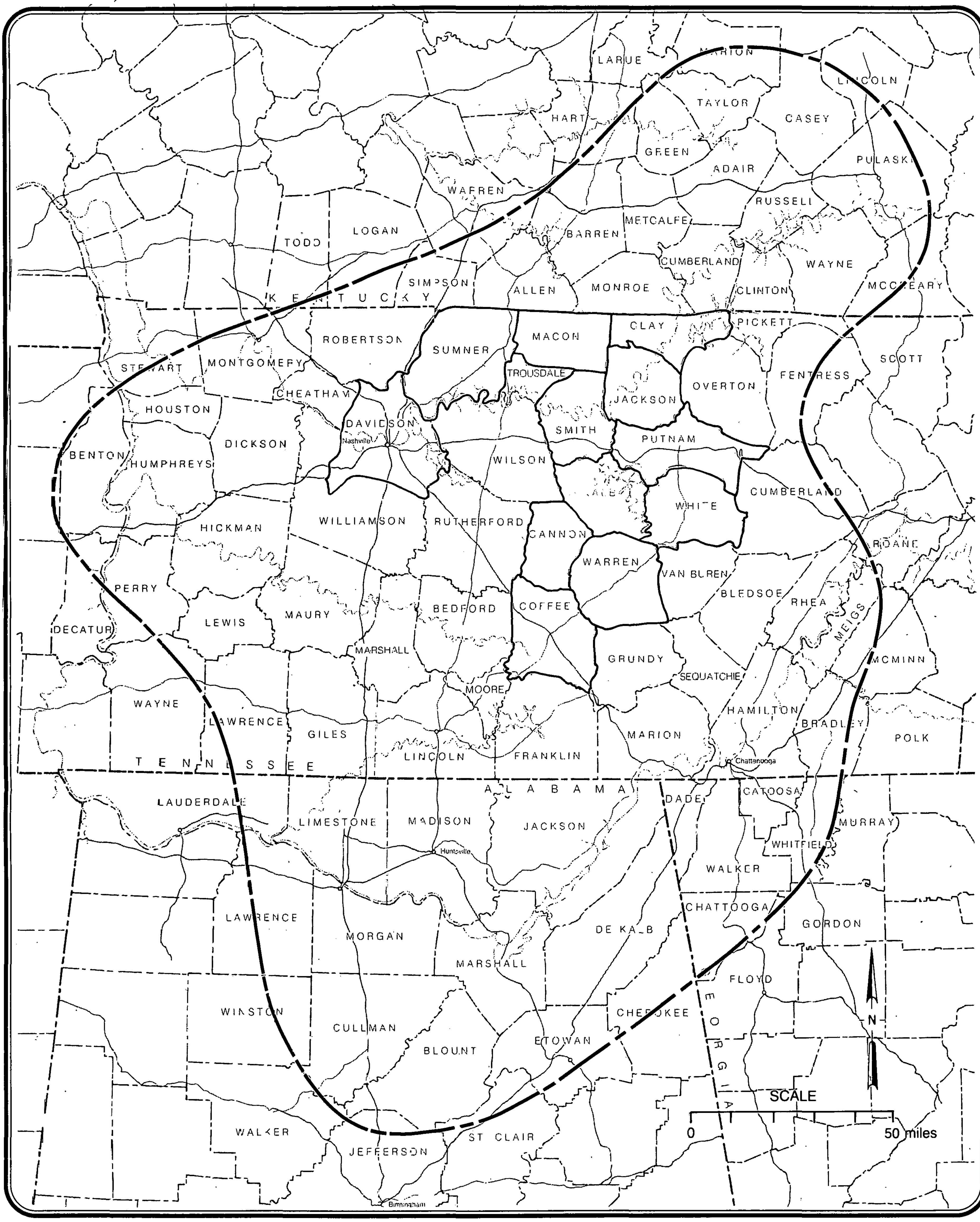


FIGURE I-4



COUNTIES WITHIN REGIONAL STUDY AREA FOR WHICH URANIUM RESOURCE ESTIMATES OF THE GASSAWAY MEMBER HAVE BEEN DETERMINED
(adapted from Mutschler, _et al._ [1976])

KEY

– · – Area with determined estimates

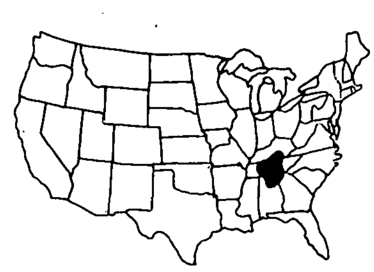


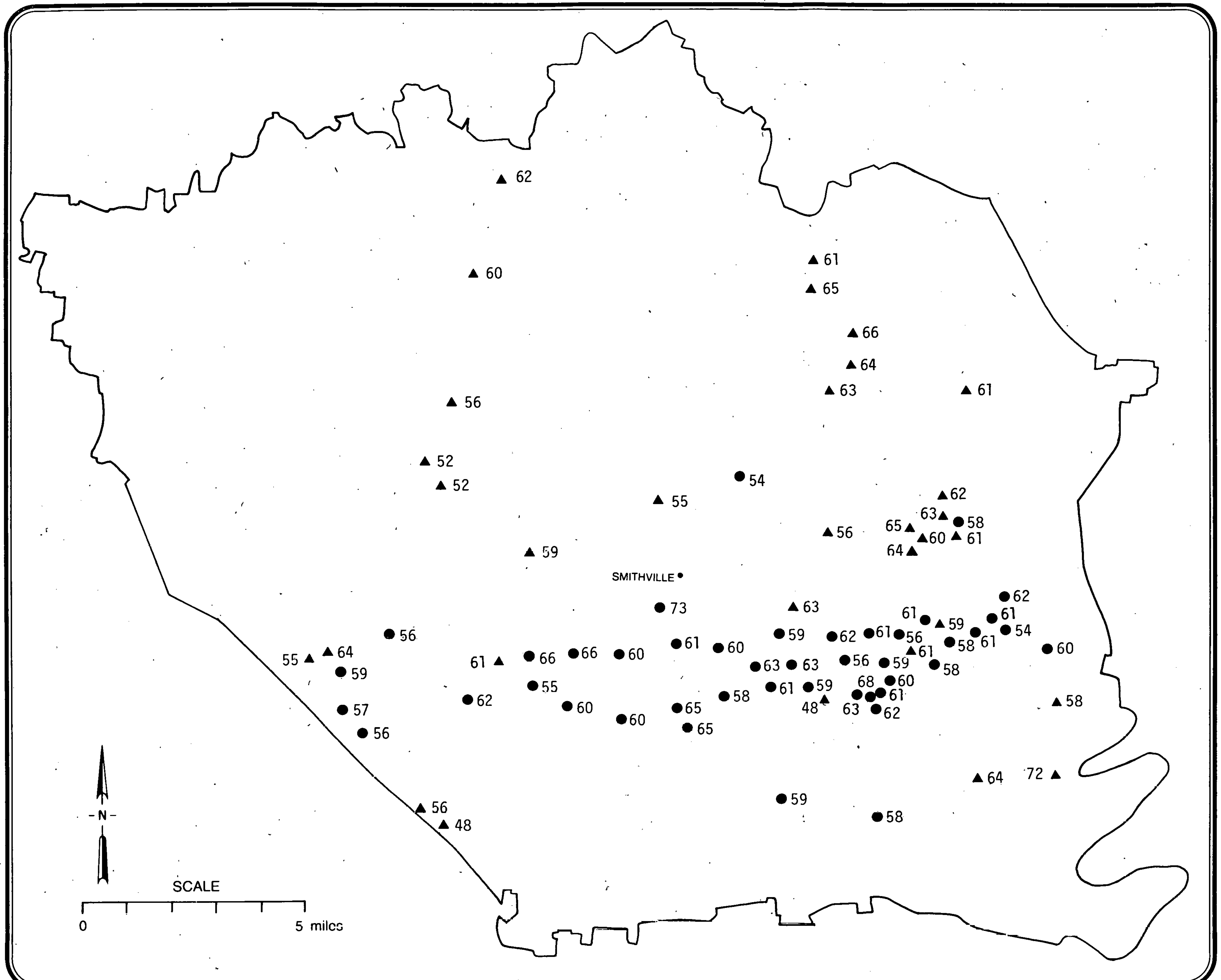
FIGURE I-5

since 1944 is the result of analyses and measurements of 222 localities within this area presented in the data compilation of Mutschler, et al. [1976].

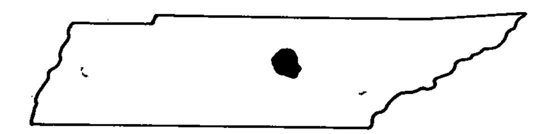
The requirement for this current study entails an assessment of the feasibility of mining, processing, and producing the shale for its mineral content, thus necessitating the choice of a "typical" area upon which to base the physical parameters of the exploitation unit. Inevitably this choice must be the Youngs Bend area of DeKalb County, Tennessee because of its relative abundance of geological, analytical, and engineering data (Figures I-6 and I-7) [Hickman and Lynch 1967; Kehn 1955]. Thirty-six of the holes drilled during the USBM exploratory program were concentrated in this area.

In DeKalb County there are 169 square miles underlain by the Chattanooga Shale, 109 thickness observations with a mean of 14.91 feet, and 78 observations of uranium content with a mean of 60 ppm. This area contains, in place, 4.7 to 5.4 billion short tons of shale and, at 60 ppm uranium content, 280,000 to 323,000 short tons of uranium [Mutschler, et al. 1976]. Oil yield values by the Fischer Assay procedure from 7 localities in DeKalb County average 8.7 gallons per ton (Figure I-8) in the Gassaway member. This appears to be normal for the central portion of the Eastern Highland Rim [Mutschler et al. 1976].

The area is also the site of the former Sligo Adit, driven into the upper, or "E," unit of the Gassaway member a distance of 100 feet, 5 feet wide, and about 9 feet high for the purpose of providing bulk samples and making observations of mining conditions and physical factors [Brown 1949]. This is the only known underground excavation in the Chattanooga and is now reported caved. The USBM recommended four alternate experimental mine sites in this area at the time based upon favorable engineering factors [Hickman and Lynch 1967; Mutschler, et al. 1976; Russell and McKinney 1954].



URANIUM VALUE OF THE GASSAWAY MEMBER AT SAMPLE LOCALITIES IN DEKALB COUNTY (adapted from Mutschler, et al. [1976])

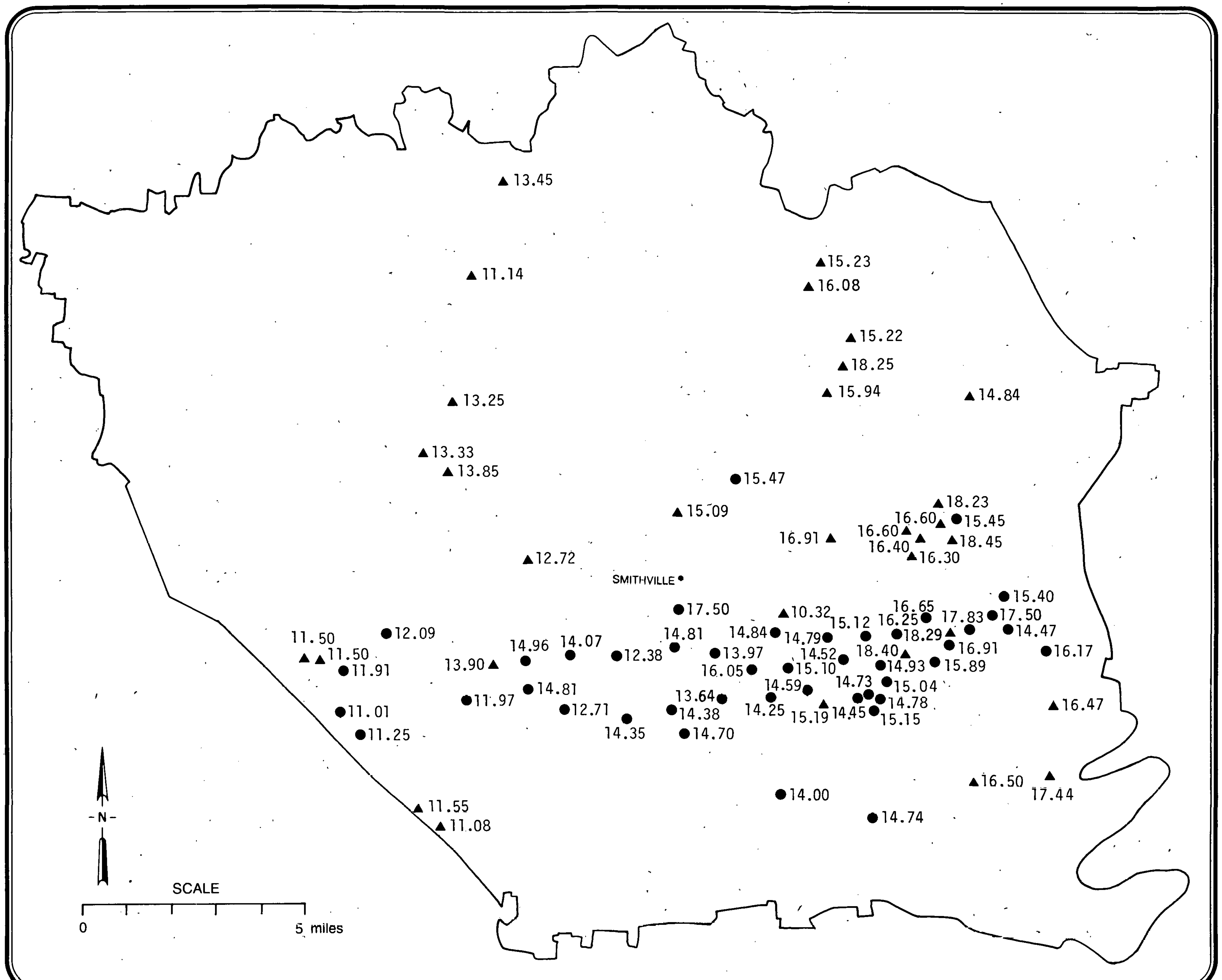


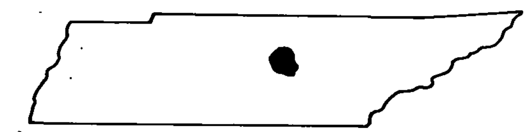
KEY

- ● Drill Hole
- ▲ Outcrop
- 66 Uranium assay (ppm), weighted average. 66 ppm = 0.0066%

FIGURE I-6

THICKNESSES OF THE GASSAWAY MEMBER AT SAMPLE LOCALITIES IN DEKALB COUNTY (adapted from Mutschler, et al. [1976])

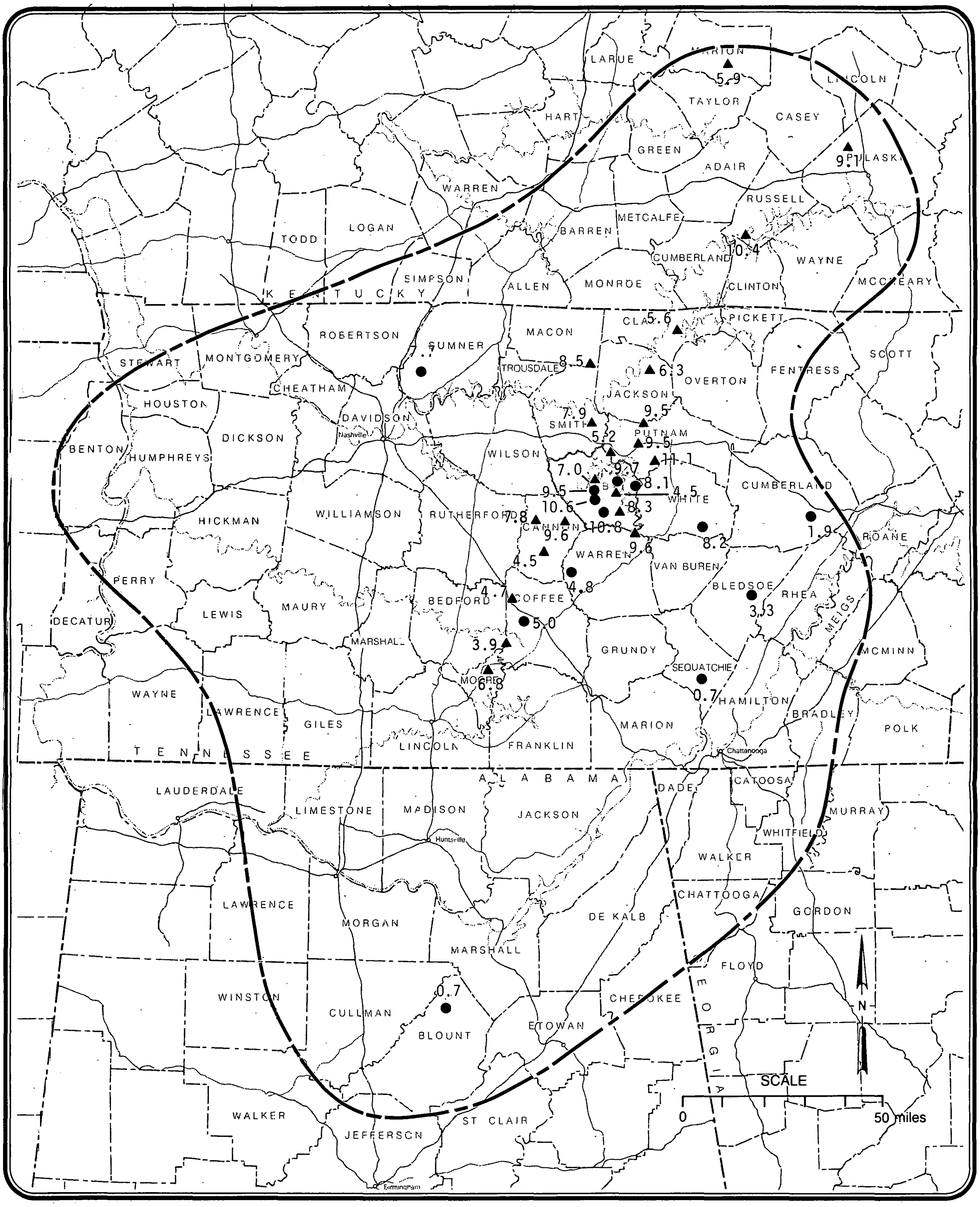




KEY

- ● Drill Hole
- ▲ Outcrop
- 14.00 Thickness of Gassaway Member (feet)

FIGURE I-7



OIL YIELD VALUES WITHIN REGIONAL STUDY AREA FOR THE GASSAWAY MEMBER (adapted from Mutschler, et al. [1976])

KEY

- ● Drill Hole
- ▲ Outcrop
- 9.5 Oil assay, weighted average (gal/ton) [Fisher Assay basis]

FIGURE I-8

SHALE STRATIGRAPHY

The Chattanooga Shale formation is a massive, siliceous, pyritic black shale of Late Devonian Age lying uncomformably on the Ordovician Leipers Limestone formation [Kehn 1955]. Its usual average thickness is somewhat over 30 feet (Figure I-9). It consists of two members: a lower member, the Dowelltown, and an upper member, the Gassaway.

The Dowelltown member is 15 feet thick and carries small uranium values, 28 ppm in the lower, or "A," unit of 6 feet. The upper, or "B," unit, of 9 feet, is usually 11 ppm, which is lean and does not warrant consideration in this study. The nominally 15 foot Gassaway member has a lower unit, "C," 7 feet thick overlain by the "D" unit, 2 to 4 feet thick, composed of mixed bands of claystone and black shale variable in uranium content. The top Gassaway unit, "E," usually but not always the best in uranium grade, is 5 to 12 feet thick. Overall in this area the Gassaway contains 60 ppm uranium. In some areas the "E" unit contains phosphate nodules in its uppermost foot.

Presently it is believed that the Gassaway member of the Chattanooga Shale formation is the only strata of mineral significance. The uranium content of this member varies between 55 and 70 ppm. Its thickness measures between 5 and 18 feet, but is mostly 14 to 16 feet. There appear to be general geologic trends of thinning and thickening from the average but more information is needed in several areas to permit more reliable interpretation.

The Maury formation, variously called shale or claystone, lies on top of the Gassaway member. It varies in thickness from 0.5 to 4 feet, sometimes contains phosphate nodules, and varies in uranium content--averaging perhaps 14 ppm.

CRITICAL FEASIBILITY CONSIDERATIONS

There are a number of important aspects which warrant recognition in an evaluation for eventual exploitation of the shale.

STRATIGRAPHIC SECTION OF THE CHATTANOOGA SHALE IN DEKALB COUNTY (adapted from Mutschler, et al. [1976])

FORMATION (THICKNESS IN FEET)	MEMBER		THICKNESS IN FEET	CHARACTER OF ROCKS
Fort Payne Chert 200±			200+	INTERBEDDED CHERT AND LIMESTONE: GREENISH-GRAY TO GRAYISH-YELLOW BEDDED CHERT AND GREENISH-GRAY DENSE ARGILLACEOUS SILICEOUS LIMESTONE.
Maury Formation 2.3			1.9±	CLAYSTONE AND SCATTERED PHOSPHATE. CLAYSTONE IS LIGHT TO MEDIUM BLUISH GRAY (FRESH), GRAYISH YELLOW GREEN TO DARK YELLOWISH ORANGE (WEATHERED); HAS BLOCKY TO SUBCONCHOIDAL FRACTURE. PHOSPHATE IN FORM OF BALLS, DISKS, AND PLATES; BALLS AND DISKS LESS THAN 0.1 FOOT IN DIAMETER; PLATES LESS THAN 0.5 FOOT IN GREATEST DIMENSION; MOST ABUNDANT AT TOP AND BASE. TOP CONTACT IS SHARP AND UNDULATING HAVING 0.1-FOOT RELIEF.
			0.4±	PHOSPHATE NODULE LAYER OF VARIABLE THICKNESS. NODULES OF MANY SHAPES AS MUCH AS 1.5 FEET OR MORE IN GREATEST DIMENSION, IN AN OLIVE-GRAY SANDY MATRIX. CONCENTRATION OF NODULES VARIES LATERALLY. WHERE NODULE LAYER IS THICKEST, OVERLYING CLAYSTONE IS CORRESPONDINGLY THINNER.
Chattanooga Shale 32.1	GASSAWAY MEMBER	UPPER	E 6.9	BLACK SHALE. SCATTERED PHOSPHATE NODULES IN UPPER 0.4 FOOT. UNWEATHERED ROCK IS GRAYISH BLACK, MASSIVE, AND BREAKS WITH CONCHOIDAL FRACTURE; WEATHERED ROCK IS MEDIUM TO DARK GRAY AND FINELY FISSILE. PAPER-THIN MEDIUM DARK-GRAY SILTSTONE PARTINGS; FILMS AND THIN LENSES OF MARCASITE.
	GASSAWAY MEMBER	MIDDLE	D 2.3	INTERBEDDED BLACK SHALE AND MEDIUM-GRAY CLAYSTONE. CHIEFLY BLACK SHALE AS DESCRIBED IN OVERLYING UNIT. AT BASE IS A "VARVED BED" APPROXIMATELY 0.05 TO 0.20 FOOT THICK CONSISTING OF THIN ALTERNATING BEDS OF LIGHT-BROWN SILTSTONE AND BLACK SHALE; THE BLACK SHALE LAYERS BECOME THICKER AND MORE CLOSELY SPACED UPWARD. BASAL CONTACT SHARP.
	GASSAWAY MEMBER	LOWER	C 7.5	BLACK SHALE. SIMILAR TO 6.9-FOOT BLACK SHALE UNIT ABOVE. A FEW THIN LAYERS OF MEDIUM-GRAY CLAYSTONE NEAR BASE, SUGGESTING THAT LOWER CONTACT IS GRADATIONAL.
	DOWELLTOWN MEMBER	UPPER	B 9.2	CENTER HILL BENTONITE BED. INTERBEDDED MEDIUM LIGHT-GRAY CLAYSTONE AND DARK-GRAY SHALE BEDS COMMONLY 0.1 TO 0.4 FOOT THICK. BENTONITE BED, 0.09 FOOT THICK, HAS CONSPICUOUS BIOTITE FLAKES; OLIVE GRAY WHERE FRESH, PALE YELLOWISH ORANGE WHERE WEATHERED AND READILY OBSERVED ON FACE OF OUTCROP; TOP IS 0.85 FOOT BELOW TOP OF UNIT.
	DOWELLTOWN MEMBER	LOWER	A 6.2	BLACK SHALE. GENERALLY RESEMBLES 6.9-FOOT SHALE UNIT ABOVE, COLOR RANGING FROM GRAYISH BLACK TO DARK GRAY. POORLY SORTED BASAL SANDSTONE PRESENT AT MOST PLACES. AVERAGES ABOUT 0.02 FOOT THICK; CONTAINS VERY FINE GRAINED CLEAR QUARTZ, IRON SULFIDE, WATERWORN CHERT AND SHELL FRAGMENTS, AND CONODONTS. BASAL CONTACT SHARP BUT SLIGHTLY UNDULATING, TRUNCATING UNDERLYING LIMESTONE AT AN ANGLE OF 1^{o} OR LESS.
				Unconformity
Leipers Limestone 50±				LIMESTONE, BLUISH-GRAY, AND ARGILLACEOUS; LIGHT-GRAY TO BLUISH-GRAY CALCAREOUS SILTSTONE IN LOWER 30 FEET. WEATHERS GRAYISH ORANGE TO YELLOWISH GRAY.

FIGURE I-9

MINERAL OWNERSHIP

It is beyond the scope of this report to deal with the basis of ownership of the shale since, as far as is known, no major portion of it is in the public domain. However, for the purposes of economic analysis, an estimate of $2.00 per ton for land acquisition and royalties has been added to operational costs. This estimate is based upon the general type of land involved and its similarity with coal lands of roughly the same energy content.

PRODUCTION VOLUME

The exploitation of this resource, if possible at all, will have to be based upon large volume and maximum efficiency in order to produce at minimum cost. Patterns for this practice are present in the large, low-grade U.S. copper facilities, both open-pit and underground.

A throughput shale tonnage of 100,000 tons per day in the beneficiation plant has been chosen as necessary and possible on a reliable daily basis with present equipment and best technology.

MINING METHODS

Surface Mining

In the recovery of some minerals, open-pit methods in many cases permit exploitation of low-value or low-grade deposits because of the economy of that form of mining. Open-pit methods would be an advantageous approach to mining the Chattanooga Shale if physical conditions of the resource were amenable to these methods. Unfortunately they are not. The ratio of overburden thickness to shale thickness is too great for open-pit mining of any areas except perhaps for contour stripping of relatively small tracts in the drainage valleys. There are favorable stripping areas for large tonnages in Kentucky but the uranium content is only 10 to 40 ppm, with perhaps 15 to 40 gallons of oil per ton by hydroretorting [Robeck and Conant 1951; Institute of Gas Technology 1977].

A greater problem is the hardness and toughness of the overlying Fort Payne Limestone formation which varies in thickness up to 200 feet. Direct observation of recently acquired core material leads to the conclusion that moving (i.e., drilling, blasting, handling) this rock in large amounts would be far more expensive than underground mining.

More detailed investigation might disclose small areas where the Fort Payne has weathered sufficiently to become soft enough to excavate. Perhaps such areas could be mined first to provide in-transit storage for slurried tailings enroute to eventual backfill underground.

Underground Mining

Using the DeKalb County area (Figures I-6 and I-7) as the typical or model area, and given the stratigraphic mode of the uranium occurrence there (Figure I-9), the ideal horizon for underground mining is of course the Gassaway member, nominal average 15 feet thick, 60 ppm uranium.

The Fort Payne will provide an excellent mine roof [Brown 1949] and allow for a heading, or working place, width of 32 feet. This is of great importance in the design of a low cost, efficient mining plan. It is necessary to provide a safe and easily accessible working face not cluttered by roof supporting timbers. Ease of access is required with side and top clearance permitting the use and easy maneuverability of the largest workable drilling and mucking equipment [East and Gardner 1964; Leach 1975].

The Maury presents a problem. Based upon the experience of the mining consultants to this study and those who worked in the Sligo adit [Brown 1949] the mining plan and costs reflect mining the Maury along with the Gassaway even though the mining horizon is thereby increased to 16 feet in thickness and the uranium grade reduced to 55 ppm. To attempt to selectively mine the Gassaway and Maury separately would impose an unacceptable economic penalty.

In Situ Mining

The question always exists as to the possibility for in situ recovery of the mineral values to reduce mining costs and damage to the environment. The concept presented in this report for the recovery of both oil and uranium would require an extremely advanced in situ technology to first retort the shale underground in a hydrogen atmosphere and then dissolve the uranium from the retorted shale with sulfuric acid. The present state of technology does not suggest the development of such capability in the near future. Further, it appears that in situ oil recovery [Cook 1974; Miller and Nichols 1973; Reynolds 1975; Rothman 1975] is best adapted to much thicker deposits than the 16 foot Gassaway or even the 40 foot thick Chattanooga including the Dowelltown member.

Present success with in situ uranium recovery in Texas is due to the mode of the mineral occurrence in permeable sandstone, greatly different from the dense fine-grained shale of the Chattanooga.

MULTIPLE PRODUCT RECOVERY

Previous writings on the feasibility of uranium production from the Chattanooga Shale have almost always alluded to the necessity for recovery of several products because of its low uranium grade [Mutschler, et al. 1976]. Recovery of the oil as well as the uranium present in the shale is still considered a requirement. This is currently a much more realistic possibility because of recent successful research work carried out at the Institute of Gas Technology (IGT) [Institute of Gas Technology 1977] with primary interest in the use of Eastern shales as a source of oil. This work has shown that the Fischer Assay, a common measure of shale oil content, is not reliable for Eastern shales like the Chattanooga when they are hydroretorted. In fact, indications are that up to 2.5 times as much oil is recoverable as determined by that assay; thus the Chattanooga in DeKalb County with a Fischer Assay of only 8.7 gallons of oil per ton of shale will in reality produce perhaps as much as 21.7 gallons per ton [Institute of Gas Technology 1977].

The IGT method involves a retorting operation carried out in a hydrogen atmosphere which produces also, in addition to the oil, sufficient hydrogen for the reaction, sulfur, and significant amounts of ammonia. Additional sulfur from the shale is recovered in a later processing step prior to acid leaching. These two recoveries will provide more than enough sulfur to make all the sulfuric acid for leaching, as well as providing significant amounts of heat energy.

This then indicates the possibility of recovery, in addition to the uranium, of important amounts of oil and ammonia. Additional research could define the possibilities for recovery of metals, such as molybdenum, vanadium, and others.

WASTE MANAGEMENT

Process Wastes

Wastewaters generated by mineral processing can be treated to remove residual organics. The high concentrations of inorganics preclude the discharge of wastewaters to the environment. The two options available for disposal of liquid wastes are: 1) concentration and evaporation to dryness, and 2) deep well injection.

Tailings Wastes

Transportation and disposal of an anticipated tailings production of 80,000 tons/day constitute a key requirement of a successful operation. Tailings waste will consist of material that will have been retorted to extract oil, and ground and leached with sulfuric acid to extract uranium and possibly other metals. Its final state is expected to constitute a 50 percent shale/water slurry.

The mine plan has been designed with the assumption that 70 percent of the tailings can be backfilled into the old mine workings leaving the remainder for disposal on the surface. It is recognized that this procedure is not currently in use to any significant extent in the mining of relatively flat-lying deposits, however, from an environmental standpoint it is considered necessary [Jankousky 1977].

Backfilling, as visualized, will be accomplished by a substantial competent system to distribute tailings slurry to the worked out areas after cessation of all production activities. The slurry will be pumped overland, down into the mines through boreholes, and into a distribution pipe grid to begin filling initially in the lowest area of the worked-out panels. This will function to deposit the greatest volume of solids by taking advantage of the slight regional dip of the Gassaway. As the lower abandoned openings become filled and the solids settle, supernatant liquid will be drained out through a pipe drain system and pumped for recovery back to the leaching circuit.

As indicated, the tailings slurry will likely be extremely "soupy", a characteristic conducive to pumping for distribution through the tailings handling system but problematic to ultimate disposal. If the solids do not settle satisfactorily in the backfill, it will be necessary to find some method of inducing settling, perhaps an adaptation of the work of Sprute and Kelsh [1976a] on fine coal slurry. There are indications that technology involving the use of electrokinetic energy to densify such slurries is advancing to a point approaching functional reality [Sprute and Kelsh 1975 a, b; 1975 a, b; 1976 a, b].

Another possibility described by Snyder, et al. [1977] is the use of a proprietary additive which has been used in fine coal slurries to "produce a solidified mass with dependable engineering properties." It is claimed that the resulting densified fines are impervious to leaching. Persistent research with a variety of minerals by suppliers of flocculants has resulted in the past in the discovery and use of new materials for this purpose with greatly improved technical results.

It is important that tailings particles settle within a reasonable time. Without substantial water reclamation from the treatment circuit (tailings stream) it will be difficult to impound the resultant huge volumes of water and fines as a mixture either underground or on the surface.

Even with tailings backfilled to the mine it will be necessary to dispose of at least 30 percent of the total tailings volume on the surface. On a weight basis this will amount to over 20,000 tons or about 10 acre-feet/ day. It appears from an engineering perspective that the most convenient disposal sites are large, normally dry valleys which over time could be completely filled, covered with topsoil, and reseeded to grasses or trees. The environmental implications of such a major landform and ecologic alteration are many and will require detailed site specific investigation.

Tailings, whether stored on the surface or underground, will be subject to leaching by rainfall and groundwater. This may represent the greatest threat posed by the contemplated uranium operation to the environment. No direct analyses of such tailings are available, but it is conjectured that process liquid adhering to the tailings particles and subsequently leached to streams or aquifers will be saturated with $CaSO_4$ (gypsum) by the use of lime and sulfuric acid in the uranium recovery process. It is assumed that minor amounts of unrecovered metals probably would be in the hydroxide form and hopefully inactive. This problem warrants further research.

SUBSIDENCE

Another reason for employment of underground backfilling is to ameliorate a surface subsidence problem should it occur. The mine openings and pillars have been designed to hold the overlying strata in place and allow no subsidence. However the space over the pillars of Gassaway Shale and the strong Fort Payne Limestone roof will be occupied by the Maury Claystone. This formation is not regarded as predictable in strength as the other formations in the mining horizon [Brown 1949].

The mines are expected to be wet; the Maury over the pillars carrying greater unit weight pressure after removal of the shale may tend to squeeze out into mined-out rooms thus allowing some degree of surface subsidence, perhaps not great or even noticeable [Cochran 1971; Parker 1973]. The capability to emplace tailings in the mine openings with even a fair degree of compaction would tend to lessen surface subsidence by restraining the movement of the Maury and perhaps eventually even absorbing some of the downward pressure of the overlying strata should it occur.

RECOMMENDATIONS FOR FURTHER STUDY

The work statement for this project categorizes Phase III, not included in this project, as the platform for recommendations. However there are several subjects which should be suggested for future work only in generalities at this time, and with a more precise definition in the eventuality of a Phase III program.

In the earlier times of the work of Kehn [1955], Stockdale and Klepser [1959], Hickman and Lynch [1967], and others, the principal objective was to find an area which combined all the prime aspects of uranium content, shale thickness, and other factors contributing to the best economy of exploitation [Gardner and McKinney 1954]. Mutschler, et al. [1976] addresses more consideration to environmental implications which in later years have assumed such critical importance.

The DeKalb County area near Sligo and Smithville, necessarily selected as the focus of this report, is also the site of the Center Hill Reservoir, source of potable water for the area. In addition the reservoir has become a recreational area for fishing, camping, and water sports. The concept of establishing a large-scale mineral recovery operation near such a body of water raises complex environmental issues.

It is suggested that a well-conceived program combining exploratory drilling with a regional environmental sensitivity overview study could perhaps disclose a geographic area of similar geology which would produce the same technical results with fewer environmental issues. Conceivably such an investigative program could disclose areas where strip mining might be feasible [Mutschler, et al. 1976].

Similar to the early work performed to determine proper working programs in Western oil shale [East and Gardner 1964; Marshall 1974; Obert and Merrill 1958; Zambas 1972], consideration should be given to establishment of a pilot operation to test mining, beneficiation, and tailings handling technology, and to gain knowledge of the effects upon the environment of procedures, techniques, and practices proposed in this feasibility study.

SECTION II
GEOLOGY

The purpose of the geological study of the Chattanooga Shale is to determine whether there are areas within or close to Tennessee underlain by uranium-bearing shale of such grade and of such tonnage as to constitute mineral deposits amenable to commercial extraction, or to constitute potential mineral resources which closer-spaced drilling might disclose as reserves. Any anticipated commercial extraction should be predicated upon prices for uranium which might reasonably be prognosticated as likely to prevail within the next ten to thirty years.

Evaluation by the geologist that such blocks of mineral indeed constitute future commercial ore is contingent upon, among other things, a) the effectiveness of a mining method, b) compatibility with acceptable disturbance of the land, water, air, and works of man (what is normally called "the environment"), c) by-products with values either commercial or essential to the national interest, and d) effective winning of the uranium and by-products by feasible extractive processes. In other words, the geologist can determine to the best of his ability what blocks of mineral may be available, but the miner, the environmental engineer, and the mineral processor or metallurgist must determine the practicability of working the deposit.

GEOLOGICAL CHARACTER OF THE CHATTANOOGA SHALE AND ADJACENT STRATA

This Devonian shale underlies large areas of Kentucky, central Tennessee, and Alabama. The same shale or its equivalent underlies large sections of the United States from Oklahoma to West Virginia, and from Alabama to New York. Similar Devonian shales are found in the western U.S., western Canada, and Alaska. This formation is described in great detail in a large number of publications, a few of which are listed in the bibliography.

Only those characteristics of greatest importance to this study are discussed herein.

The shale is marine. The wide variety of mineral constituents in the Chattanooga, particularly such metals as V, Pb, Sn, Zn, Co, Ni, Ag, Be, Cu, and Mo in amounts greater than in many other shales [Mutschler, et al. 1976] can hardly be treated here without embarking upon complex considerations far beyond the practicalities of this report. The divergence from the norm in metal content (without considering U and Th) would be expected in comparing marine shales with terrestrial shales, but in comparing marine with marine the relatively high amounts of these metals in the Chattanooga seems surprising. It is uncertain whether this divergence is due to the same processes which resulted in the precipitation of uranium.

ATTITUDE

In central Tennessee, the area under study (Figure I-1), the Chattanooga Shale where not eroded away is relatively flat-lying west of the Appalachians. In the eleven-county area of the Nashville Basin the Chattanooga has been removed by erosion. To the west and northwest of the Basin the dips are flat or possibly westerly. To the east and southeast of the Basin the Chattanooga dips 10 to 15 feet per mile to the southeast. In a few restricted areas dips may reach 10° to 15° but quantitatively these are of minimal importance. Further into eastern and southeastern Tennessee the flat dips are interrupted by the folding and faulting of the Appalachians (Sequatchie Valley, Waldon Ridge, etc.).

STRATIGRAPHY

The stratigraphic section immediately above and below the Chattanooga may be briefly summarized. In succession, proceeding upward, the Chattanooga Shale is overlain by approximately 1 to 4 feet of Maury Shale, or claystone; up to 250 feet of cherty Fort Payne Limestone, in places shaly, particularly to the north and northwest of the Nashville

Basin; up to 120 feet of Warsaw Limestone; up to 140 feet of St. Louis Limestone; up to 320 feet of Monteagle Limestone; up to 70 feet of Hartselle Sandstone; up to 130 feet of Bangor Limestone; up to 300 feet of Pennington formation (limestone, sandstone, shale). From the Maury up through the Pennington the age can be considered Mississipian.

In succession, proceeding downward, the Chattanooga Shale is underlain by Ordovician rocks: Leipers and Catheys Limestone and Siltstone up to 270 feet, Bigby-Cannon Limestone up to 120 feet, Hermitage Limestone up to 100 feet, Carters Limestone up to 110 feet, Lebanon Limestone.

From Marion County, Kentucky to Blount County, Alabama, and from Cheatham County, Tennessee to Cumberland County, Tennessee (Figure I-1) the Chattanooga Shale varies in thickness from zero to about 40 feet. Individual units and members also vary in thickness. The formation is commonly divided into an upper Gassaway member and a lower Dowelltown member (Figure I-9).

The Dowelltown member consists of a lower (A) unit, in many places about 6 feet thick, and an upper (B) unit about 9 feet thick. "A" is in many places blacker and richer in uranium than "B", which is shale and claystone. In estimating content of uranium it has been common practice to ignore the Dowelltown; even if "A" carries pretty fair values, "B" is low and reduces most averages drastically. Less than 1 foot from the top of "B" is a 1-inch layer of bentonite which serves as a useful geologic marker.

The Gassaway member has a 7-foot thick lower black shale unit (C), in many sections assaying as much or more in uranium than the upper black shale unit (E), or "Top Black." The "Top Black," 5 to 12 feet thick, is reputed to have the best grade in uranium although this is not universally true. On the Eastern Highland Rim from DeKalb County northward phosphate nodules are common in the top 1 to 3 feet and this rock is relatively lower in uranium. The middle Gassaway unit (D) is claystone alternating with black shale; it is 2 to 4 feet thick and, being lower in uranium than the units above and below, frequently presents a problem to the engineer trying to arrive at a satisfactory average grade for the section. If "E" does not present an attractive mining thickness, "D" and "C" will be included, resulting in many instances in a lower grade.

The overlying Maury formation, 0.5 feet to 4.0 feet thick, is Devonian, Mississippian, or both in age (only about 10 percent of the measured sections in Tennessee have Maury of over 3 feet in thickness). In some sections it resembles the top part of "E" where the latter is high in phosphate nodules. In general, however, it is green rather than black, and a claystone rather than a shale.

Following is a discussion of some of the geologic characteristics of the lower Fort Payne formation, the Maury formation, and the Chattanooga Shale formation.

Fort Payne Formation

The Fort Payne formation is a cherty limestone with considerable shale content in areas north and northwest of the Nashville Basin. There are many variations so that at one spot there may be chert alternating with beds of argillaceous limestone, at another limestone with contained chert nodules, and at another some other combination. Of importance to this study are two questions: a) Would the Fort Payne in general present difficult digging to surface machines preparing the ground for open-cast mining?, and b) Would the Fort Payne stand well if mining were underground?

The answers to both questions appear to be a qualified yes. From the Eastern Highland Rim to the Sequatchie Valley, the area of greatest interest, most hole logs and most outcrop descriptions indicate a strong rock. In outcrops the Fort Payne presents an overhanging ledge protecting the weak Maury underneath. In drill holes the core recovery in the Fort Payne was generally close to 100 percent, even with rigid core barrel; except in the few holes where weathering or mud seams presented the barrel with hard nodules in a soft matrix.

For surface digging, even weathered Fort Payne would present difficulties because of the chert nodules. Underground it can be presumed that right at the outcrop there will be sloughing, but that once the working has progressed 25 to 50 feet [Brown 1949] the roof will stand well unless the Fort Payne cap is very thin (20 to 30 feet). The Fort Payne is jointed, so where it is strongly argillaceous percolation of water could produce a weak mine roof.

It is not possible to be entirely definite about a rock, particularly a formation as varied as the Fort Payne, but it seems fairly certain that underground mining methods can be adapted to conform to any local peculiarities of the Fort Payne roof and that this formation will provide a satisfactory roof.

Maury Formation

The Maury is a clay shale; it may not show significant laminations and some geologists call it a "claystone." In and near central Tennessee it is commonly 0.5 to 4 feet thick and averages about 2 feet. Considering extremes, the Maury is 0 to 6.1 feet thick. Important to this study are three important characteristics of the Maury: 1) low strength, 2) plentiful phosphate nodules, and 3) low content of uranium. A brief discussion of each of these three characteristics follows.

Ball-bearing core barrel produces much better core recovery in soft formations than the standard, rigid barrel. Drilling with ball-bearing core barrel in the early 1950's produced good to poor core recovery in the Maury whereas standard barrel gave mostly excellent recovery in the Fort Payne. With reference to the Sligo Experimental Adit, Brown [1949] states: "The green shale shows many signs of being a poor roof rock. ....the Fort Payne in general makes a good roof except near the outcrops, where it is likely to be broken because of slumping of the underlying Maury." Although in some places the Maury is competent, in general it cannot be used as an underground roof. In an underground mine the Maury will be part of the ore muck pile, reducing the overall grade.

The phosphate nodules in the Maury may help mitigate the dilution in uranium grade, provided cheap extraction of phosphorus is possible; it is soluble in the acid used for recovery of uranium.

The Maury varies widely in uranium content but it averages around 14 ppm (16.5 ppm U_3O_8). If the Chattanooga were mined by surface methods it might or might not be possible to keep the Maury out of the ore. In an underground mine it would probably be next to impossible to separate the Maury. This would mean lower uranium grades for the produced ore. It would probably mean higher grades in phosphate although there is little phosphate content data for the Maury, and the nodules are distributed very erratically.

Chattanooga Shale Formation

Most cores of the Chattanooga show the fresh rock to be fairly massive although banding is visible. However, the Chattanooga easily breaks into plates along bedding planes. In outcrop the Chattanooga is universally described as fissile. Sandy zones and silty zones, commonly less than 2 inches in thickness, are found at two or three positions in the section, including the base, but these zones probably average less than 0.7 percent of the total section.

Dips are commonly less than 15 minutes (to the SE on the Eastern Highland Rim). Of 240 sections described in detail at outcrops by Stockdale and Klepser [1959] one outcrop shows a dip of the Chattanooga of over 1°. This is in Clay County; the strike is N 55° E., and the dip is 15° to 20° to the NW. One section in Sumner County shows a northerly dip of the Dowelltown, but it is truncated by the Gassaway which is virtually horizontal. In a few outcrops the underlying Leipers (Ordovician) dips 5°, 10°, 15°, etc., but the Chattanooga overlying this angular unconformity has its usual flat dip. Locally within the Chattanooga there are appreciable dips on internal structures, internal contortion, "roll" structures, cross-bedding, etc., but these do not affect the extremely flat average dip of the Chattanooga as a whole, or the Gassaway in particular.

For practical purposes it is fairly certain that any mining of the Gassaway, or entire Chattanooga, in the area between the Nashville Basin and the Sequatchie Valley will be on a bed dipping less than 1/2° to the southeast, with very few, if any, local dips greater than 5°.

The Chattanooga is not present in a small area of Moore County, Tennessee. From this 0 feet thickness the Chattanooga reaches or surpasses 40 feet in southern Kentucky and northern Alabama. The Flynn-Creek structure, in which the lower (Dowelltown) member of the Chattanooga thickens to 180 feet, is a strictly local phenomenon in south central Jackson County, Tennessee. It is described by Stockdale and Klepser [1959]. The upper member, the Gassaway, ranges from 0 feet in a part of Moore County to 33.6 feet in Blount County, Alabama and 38.75 feet in Pulaski County, Kentucky.

Much of the overburden on top of the Chattanooga is 150 to 250 feet thick. As the formation becomes deeper to the south the overburden reaches 400 to 500 feet. Eastward, with the formation dipping ± 10 feet per mile, the depths to the top of the Chattanooga are 350 to 600 feet, and from the tops of the higher mountains, 1,000 feet. Under the Cumberland Plateau, about 14 miles east of DeKalb County, the Chattanooga is probably 1,500 to 2,000 feet below the surface although the author has not searched drill-hole records for this area.

It is said that the Gassaway has a greater areal extent than any other subdivision of the Chattanooga. An average thickness of 14.73 feet in 222 localities is given by Mutschler, et al. [1976]. As noted previously, all five units (A to E) of the Chattanooga are not recognizable everywhere.

The Chattanooga is relatively strong. It was found in the Sligo Experimental Adit that the main problem with sloughing came from breaking away from prominent vertical joint planes [Brown 1949].

MINERAL CONTENT

According to Swanson and Kehn [1955], the results of careful vertical and horizontal sampling at short intervals, and general regional comparisons make it apparent that changes in grade of uranium in the Gassaway are gradual, if any; they are not abrupt.

Phosphate in the Chattanooga is present in the nodules so common near the top of unit "E" ("Top Black") from DeKalb County northward. It is also present throughout the rest of the section as apatite grains. Averages in ten holes and four outcrops, evenly scattered along the Eastern Highland rim from Marion County, Kentucky to Birmingham, Alabama, show 16.65 feet of Gassaway running 0.36 percent P_2O_5 [Mutschler, et al. 1976]. Unweighted results are 0.37 percent P_2O_5 (five samples from the Dowelltown suggest that P_2O_5 assays might be somewhat lower than in the Gassaway). No correlation is apparent between grade of U and grade of P_2O_5 in the same samples.

Assays of the narrow zone of phosphate nodules at the top of the "E" unit are not available, but one might expect it to be higher grade than 0.37 percent. Determination of an exact average grade for P_2O_5 in the Top Black (and in the Maury) will be difficult because of the erratic distribution of the phosphate nodules.

The blackness of some units of the Chattanooga has resulted in its being called an "oil shale." The brownish cast of the blackness has resulted in others calling it a "bituminous shale." Recovery of oil from 34 samples of the Gassaway taken from Kentucky to Birmingham showed seven gallons per ton over 16.65 feet as determined by Fischer assay [Mutschler, et al. 1976]. There is no correspondence noted between the oil recoveries and the uranium assays from the same samples. Increased oil recovery by use of hydroretorting is discussed elsewhere in this report.

Iron sulfide (FeS_2) is an important constituent of the Chattanooga, running from 5 to 15 percent [Mutschler, et al. 1976]. Stockdale and

Klepser [1959], quoting Bates and Strahl of Pennsylvania State University, show the following list of minerals in a batch sample of Chattanooga:

Quartz	22 Percent
Feldspar	9
Illite and Kaolinite	31
Organic matter	22
Pyrite and Marcasite	11
Chlorite	2
Iron oxides	2
Tourmaline, Zircon, Apatite	1
	100 Percent

This amount of iron sulfide would provide the acid needed for the leaching of uranium and possibly other by-products.

Mutschler, et al. [1976] reports 0.08 percent V (0.14 percent V_2O_5) from 61 assays of Gassaway from two drill holes. Perhaps half of this vanadium will go into solution in an acid leach. The same investigators report thorium assays from seven holes through the Gassaway in Tennessee and one in Alabama. The weighted average for 15.77 feet is 0.00088 percent Th, compared with 0.0059 percent U from the same intervals.

These investigators make a comparison between the distribution of 32 elements in the Chattanooga and the average distribution of the same elements in some other shales. Table II-1 presents a comparison between the Gassaway (61 samples from 2 holes) and these other shales with respect to a few of the 32 elements.

Following are the results of a mineralogical examination by Mountain States of Chattanooga Shale cores taken from Overton County, Tennessee. For purposes of the examination cores were divided into three zones represented by the following members: 1) Maury - a greenish gray, laminated, shaly claystone; 2) Gassaway - a brown-black, laminated, very fine-grained shale with pyrite concretions; 3) Dowelltown - a brown-black, laminated, very fine-grained shale with pyrite concretions. Three to

TABLE II-1. DISTRIBUTION OF ELEMENTS, GASSAWAY vs. OTHER SHALES

Element	Top Black	Upper Gray	Middle Black	Other Shales
Mn	.04	.06	.04	.09
Ca	.08	2.3	.2	2.21
C	12.49	3.61	13.28	--
Pb	.02	.01	.02	.002
V	.08	.07	.09	.01
Zn	.06	.04	.06	.01
Ni	.06	.04	.06	.007
U	.0087	.0027	.0058	.0004
Cu	.02	.02	.03	.005
Mo	.04	.01	.02	.0003
Mg	.5	.6	.6	1.50
K	4.8	2.6	3.9	2.66

four 2-inch core segments were selected randomly from each of these three members of the Chattanooga Shale. Three and two thin sections, respectively, were made from the Maury and the other two (Gassaway and Dowelltown) members. One polished section was prepared from one of the pyrite concretions of the Gassaway member. The thin and polished sections were thoroughly examined under transmitted and reflected light, respectively, by polarizing microscopes. The following mineralogical character was disclosed by the examination.

Quartz appears to be the predominant mineral in all the observed samples, particularly in the Maury member. It occurs in fine to very fine grains, most showing parallel orientation. The quartz is intimately associated with sericite, clay, bituminous material, gypsum, calcite, pyrite, hydrous iron oxides, etc.

Sericite and clay are a close second in frequency among the mineral components in the observed samples, particularly in the Maury member. They are present in very fine to fine flakes forming the interstices along with the bituminous material between the other minerals.

Bituminous material is present in almost the same amount as sericite and clay, particularly in the Gassaway and Dowelltown members. It is a dark to reddish-brown, opaque to translucent, compact filler without any sign of crystallinity (graininess). The bituminous material actually occurs as a cementing agent between the other grains. Since it is a compact, amorphous-looking mass, its grain size cannot be determined.

Gypsum is a frequent mineral component filling fractures, cracks, and inter-layer partings. It is fibrous and is a soft mineral of moderate grain size. Calcite is a minor mineral, which occasionally occurs in medium to large grains or grain aggregate. Pyrite is the most common opaque mineral in all the observed samples. It occurs in individual crystals (Maury) or grain aggregates (Gassaway, Dowelltown, and occasionally Maury). The pyrite is disseminated in the transparent mineral matrix. Some of the pyrite is altered to hydrous iron oxides, hence the brownish rusty color of some parts of the shale or claystone. The individual crystals are of fine to medium size (5 to 100 microns); the aggregate size may reach several thousand microns. Hydrous iron oxides occur as alteration products of the pyrite.

Limited time, and the use of equipment restricted to the light microscope only, adversely influenced the identification of any uranium mineral components which may occur sparsely in the Chattanooga Shale. It seems that the main source of radioactive emanation is the organic bituminous matter. Since this material is in an amorphous state, the determination of any discrete uranium-bearing compound may not be possible even by highly sophisticated methods of detection.

The rock types of the shale and claystone seem to be composed of well-sorted, densely packed mineral components which hardly would permit a free flow of leaching solutions. This may be possible along the partings (of the lamination) which provide only a lateral penetration with fairly limited surface area (depends upon the physical position of the layers in the beds). The presence of clay may also adversely influence the leaching process.

RESERVE AND RESOURCE ASSESSMENT

Of the many excellent publications listed in the annotated bibliography at the end of this report from which valuable geological information was extracted for this discussion, the following were of particular help in assembling the data upon which to base reasonable conclusions as to resources and reserves available for possible future mining: Hickman and Lynch [1967], Kehn [1955], Mutschler, *et al*. [1976], and Stockdale and Klepser [1959]. The geologic maps with accompanying booklets for each 7-1/2 minute quadrangle, published by the Department of Conservation, Tennessee, were indispensable in gaining an accurate picture of the Chattanooga Shale and the topography under which it lies. Dr. Harry Klepser provided much useful information and comment.

Some problems and questions with respect to applying this store of information to quantifying the resource have been singled out as follows: a) the general recommendations of some writers should be made more precise; b) the objectives of these writers were certainly not all identical; c) not all information jibes; d) are samples and assays from drill holes more accurate than those from outcrops? (discussed below); e) can the grades and thicknesses be checked back to original sources?; f) what should be done with the Maury?; g) where samples were taken at 1-foot intervals, but mixed for one composite, should an attempt be made to obtain such individual, 1-foot samples and re-assay them individually?

It is obvious from reading the reports that many different geologists and many different engineers, with a wide range of abilities and expertise, took samples over a long period of years. To try at this late date to separate the accurate from the inaccurate is impossible. However, sections of core and sections of outcrops with obvious mistakes or uncertainties can be omitted from consideration.

No matter how the problem is approached, the same general conclusions are reached. There is fairly adequate information on a portion of DeKalb County, Tennessee. Information on other areas is so scant that the only safe conclusion for such areas is that shale is present, uranium is present, and blocks of shale with average grade within 10 or 20 ppm of the values already indicated might be developed by a great deal more drilling.

Large tonnages of 60 ppm uranium (71 ppm U_3O_8) have not in the past constituted commercial reserves. With the help of recovered oil and phosphorus, such reserves in the Chattanooga are probably approaching the point of commercial consideration.

To develop an accurate estimate of reserves of the shale most favorable for mining, and also feasible economically, technically, and environmentally, will require drilling, sampling, and assaying for all elements of possible economic value. As this cannot be part of the current program, the data currently available in the four publications of reference have been relied upon, except where obviously inaccurate, incomplete, or questionable, and the averages obtained are assumed to be correct. As mineral deposits go, the Chattanooga is, after all, remarkably uniform.

INFORMATION FROM HOLES vs. INFORMATION FROM OUTCROPS

The report by Stockdale and Klepser [1959] has suggested that outcrops may be higher in uranium that the original rock. However, Klepser has stated verbally that they are generally lower. Many other workers believe outcrops would generally be lower than the original rock. Brown [1962] and others have found leaching in the upper beds of the Chattanooga at waterfalls; in some places this may result in enrichment in the lower part of the Gassaway. In any event there is very apt to be an error introduced by weathering.

Procedures described by Hickman and Lynch [1967] for handling of much of the core suggest that core samples were taken accurately. Core recovery in the Gassaway in many holes was reportedly 100 percent, or nearly 100 percent. Cores were then cut longitudinally by diamond saw. With this apparent care the samples from many holes should be correct. Only where weathering happens to have penetrated deeply, or where there is no information as to recoveries, or where the diamond saw was not used could one question the handling of the core. It would of course be difficult to determine now whether the assays used for all the holes upon which the present report bases its factual data were made on cores handled with the care and accuracy known to have been used on many of them.

For outcrops, on the other hand, obtaining an accurate sample representative of what the rock contained before exposed by erosion is much more difficult. At the outcrops studied for the report by Stockdale and Klepser [1959] channels were reportedly cut with great care, but accomplishing a uniform cut on a steep slope of varying dip, with equal amounts of material from each short unit of length, is extremely difficult. A piece of core cut by diamond saw from a section where 100 percent core recovery has been obtained has to be more accurate than material chipped out by pick from a surface outcrop. The quantitative effect of weathering can only be a guess. Normally, badly weathered outcrops were not sampled, but, at best, visual appraisal of an outcrop with respect to change in uranium content is inaccurate.

There is no way to apply a correction factor to surface assays in the hope of arriving at a more representative figure for grade. Of the 222 sections with assays listed by Mutschler, et al. [1976], two-thirds are outcrops and one-third are drill holes. To compare average grades from core holes with average grades from outcrops has its risks. One cannot compare one hole with one nearby outcrop. Groups of holes with groups of outcrops would be satisfactory if the areas were approximately the same. Mutschler, et al. [1976] states: "The effect of weathering could not be weighed in the tabulation of analyses contained in this report."

In and adjacent to DeKalb County, where most of the known holes and outcrops are located, the comparisons appearing in Table II-2 can be made. Any conclusions which one might reach on the basis of the information appearing in the Table should be tempered by the fact that the outcrops sampled are scattered over ten times the area covered by the drilling. The drill holes are located in a relatively small area. On the basis of the comparison one might arrive at one of the following conclusions: a) at an allowable error in assaying of 5 ppm, the correspondence is exact; or b) outcrops show the expectable amount of loss of uranium by leaching; or c) the correspondence is not exact because there are too few samples, and the areas are not identical; or d) the uranium assays are remarkably uniform no matter how the shale is sampled; or e) arriving at a grade for the shale by sampling the outcrops does not introduce large errors, provided outcrops are plentiful.

Apart from any superiority in accuracy of sampling by drilling, drilling provides a more dependable determination of thickness and it allows the regular spacing of samples which will ultimately be necessary before commercial production on a large scale is attempted.

TABLE II-2. COMPARISONS OF CORE HOLES AND OUTCROPS WITH RESPECT TO URANIUM GRADE DETERMINATIONS

	Unit "E" Only		
25 square miles	30 Drill Holes	5.22'	78 ppm
250 square miles	19 Outcrops	5.81'	67 ppm
	Units "C & D" Only		
25 square miles	30 Drill Holes	9.81'	50 ppm
250 square miles	17 Outcrops	7.06'	47 ppm
	Gassaway		
10 square miles	7 Drill Holes	12.57'	59 ppm
100 square miles	8 Outcrops	13.43'	55 ppm

URANIUM RESERVES AND RESOURCES IN DEKALB COUNTY

Hickman and Lynch [1967] (see their Table 1) indicate "measured reserves" in DeKalb County as part of two blocks:

Part of Block 1 (± 30 holes, a few outcrops)	approx. 15.36 square miles at 15 feet thick: 461,000,000 short tons of shale running 60 ppm;
Part of Block 5 (11? holes, very few outcrops)	approx. 19.45 square miles at 12 feet thick: 467,000,000 short tons of shale running 60 ppm.

The geographic sizes shown for the two areas are calculated on the assumption of 143.52 pounds of shale per cubic foot (in place) as these writers do not show the perimeters of the areas; however, this author does not know if they used this factor of 143.52. The square miles are derived by working back from the tonnage and thickness values shown in Table 1 of their work. The thicknesses used (15 feet and 12 feet) are those of the Table, not the actual averages carried out to hundredths.

The 15.36 square miles in Block 1 could be a rectangle, 2.0 miles N-S by 7.7 miles E-W, or an irregular area. In either shape of area, or something in between, each drill hole is within a mile of one or more neighboring holes, or as little as one-half mile. The holes are not on a regular grid but many approach such a configuration. Some 25 to 30 holes plus a few sampled outcrops were included to give the 60 ppm grade for the area.

Disregarding outcrops, 25 holes with good core recovery and at regular spacing should provide nearly adequate sampling of a block measuring 15 square miles on a flat shale bed with a uranium grade as uniform as has been found to date in the Chattanooga of DeKalb County.

In the opinion of this author eleven holes in 19-1/2 square miles is not close enough spacing to constitute "measured reserves." Thus the wisdom of calling that much of Block 5 "measured reserves" is questioned, particularly in view of the paucity and poor location of outcrop samples. This writer excludes all but the easternmost six holes in Block 5 (see Hickman and Lynch [1967], their Figure 5) in calculating what he considers "measured reserves" under roughly 17 to 18 square miles in DeKalb County (see Figure II-1). His block is bounded by the irregular perimeter shown in Figure II-1 and includes the holes of Block 1 ("measured reserves") and 6 holes (Nos. 107, 108, 110-113) of Block 5 ("measured reserves").

Using an approximate average thickness of 16.5 feet for the Gassaway plus Maury in the 18 square mile area, this author calculates the following "measured reserves":

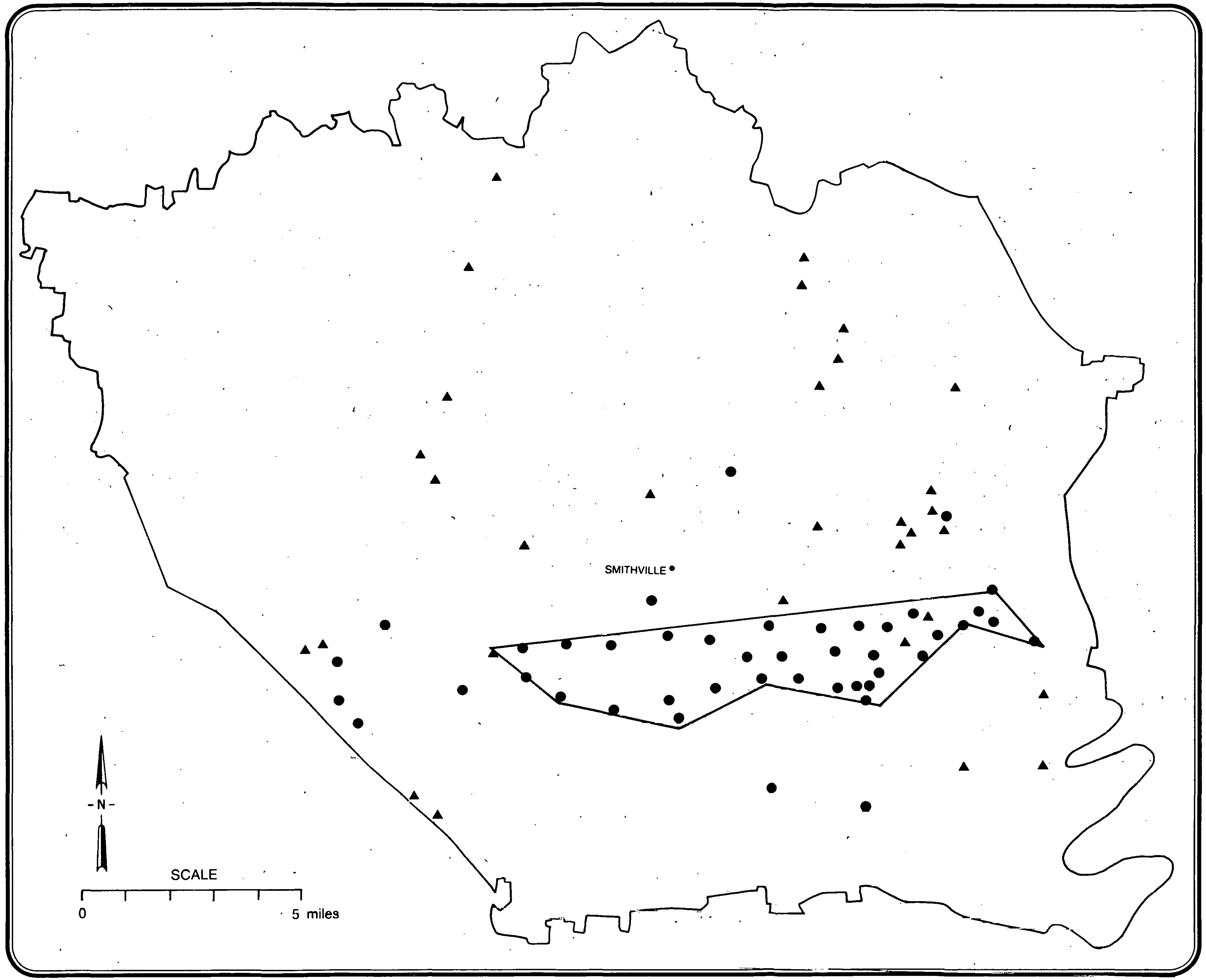
$$\frac{18 \text{ X } 5280' \text{ X } 5280' \text{ X } 16.5'}{13.935} =$$

595,000,000 short tons of shale and claystone averaging approximately 55 ppm U.

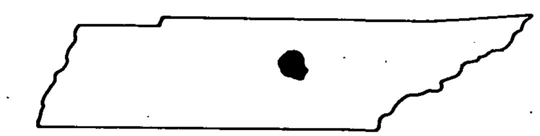
In terms of common practice, this tonnage could reasonably be termed "positive reserves" or "proven reserves," though not necessarily "commercial ore" at current prices.

"Inferred reserves" in DeKalb County according to Hickman and Lynch [1967] total 4,539 million tons under 132 miles of Block 1, plus possibly one fifth of 3,933 million tons in Block 5 (the rest being in Cannon County). In view of the wide spacing of the holes and outcrops throughout most of this 132-mile area plus the Block 5 area (samples 2 to 5 miles apart), and the use of assays of outcrop samples, "possible reserves" might be a better term than "inferred reserves," particularly when a grade value is attached to these reserves.

Mutschler, et al. [1976] gives the same general range of estimates for the total reserves or resources of DeKalb County (Hickman's "measured" plus "inferred"); the degree of correspondence in the areas used in the



EIGHTEEN SQUARE MILES OF PROVEN RESERVES IN DEKALB COUNTY (adapted from Mutschler, et al. [1976])



KEY

● Drill Hole

▲ Outcrop

FIGURE II-1

two publications is not precisely indicated. However, Mutschler uses the term "uranium resource estimates," which should translate as "estimated resources," rather than "measured" and "inferred." The term "estimated resources" probably represents a different degree of certainty to each person who gives it any consideration. However, the constant search for more precise terminology for mineral reserves (resources) is probably a blind alley.

In view of the work performed to date it is hard to disagree with Hickman and Lynch [1967] that there are in DeKalb County, Block 1, approximately 461 million tons of shale with an approximate 28,000 short tons of contained uranium in the Gassaway, plus some in Block 5. These tons are "measured" or "positive." The "inferred" tonnage, when tied to a specific grade, could be labelled somewhere in between the categories of "probable" and "possible." Mutschler, et al. [1976] acknowledge the existence of a "precise resource .... for a confined area in DeKalb County, Tennessee." They do not mention the tonnage or grade, and in their tabulation they list only the larger figures of their "submarginal uranium resource" or "uranium resource estimates" (4,247,000 to 5,083,000 short tons of U in 12 counties).

In the calculations of tonnages made by Hickman and Lynch [1967] and Mutschler, et al. [1976] the Maury has not been included as part of the reserves (or resources) even though many or most writers have mentioned that the Maury will have to be moved. Because of the physical characteristics of the Maury it is more realistic to include it as an integral part of the Gassaway for purposes of mining. Since data on the Maury are less complete than data on the Gassaway, it has been necessary in the majority of cases to use assumed values. For uranium grade, the known grade of the Maury in nearby drill holes or outcrops has been applied to the Maury in a hole or section without Maury assays. Where there are no neighboring holes or sections with known values a grade of 14 ppm has been used, as this is a fairly accurate average figure for the Maury on the Eastern Highland Rim.

The same method has been used to establish a thickness for the fewer cases where no thickness data were available for the Maury. Where the Maury is thick the average uranium grade of the Gassaway section is lowered considerably by its inclusion. This is not the case in DeKalb County where most sections show less than 1.5 feet of Maury, but in spite of this some lowering of grade does occur as shown in Table II-3.

POSSIBLE URANIUM RESERVES AND RESOURCES IN OTHER TENNESSEE COUNTIES

If and when the economics become favorable for the commercial extraction of uranium and other products from the Chattanooga Shale, there is no reason to believe from the knowledge presently available that DeKalb County should be the locus of such activity in preference to any of another half-dozen or more counties between the Eastern Highland Rim and the folded Appalachian country. This observation in no way denigrates the value of a feasibility study of the shale in DeKalb County. Any economic and mining model developed in DeKalb can be applied with modifications to other areas of the Chattanooga Shale.

If any point has become clear in the study of the Chattanooga Shale, it is that the shale is widespread and uniform and can be mined at roughly equal grade in many places. The choice of location should not depend upon the fact that more holes have been drilled in DeKalb County prior to 1978 than elsewhere. The choice should depend upon the relationship between mining and utilization of the surface by man, direct or indirect, and upon the effect of depth of overburden and other such factors upon the cost of mining. With these factors appraised and understood, either DeKalb County or some other county can be picked as the most likely target for development drilling. It is to be presumed that 18 square miles in DeKalb County is not the sum total objective of all the work expended on the Chattanooga Shale since the 1940's.

If environmental factors and/or mining considerations indicate that other places might be preferable for the contemplated operation, drilling

TABLE II-3. INFLUENCE OF MAURY FORMATION UPON URANIUM GRADE DETERMINATIONS IN DEKALB COUNTY

	Holes and Outcrops	Thickness	Uranium Grade
Mutschler, *et al.* [1976]	78 observations; without Maury	14.91'	60 ppm
Mountain States	45 holes only; with Maury [a]	14' [b]	55 ppm
Mountain States	13 outcrops only; with Maury [a]	13.5' [b]	52 ppm

[a] Only those sections are included which appear to be accurate.
[b] This lesser thickness (in spite of adding the Maury) is due to excluding the lower and middle Gassaway in holes where they average less than 50 ppm; if included, the thickness would be over 16', but the grade would be less than 55 ppm (less than 52 ppm for outcrops).

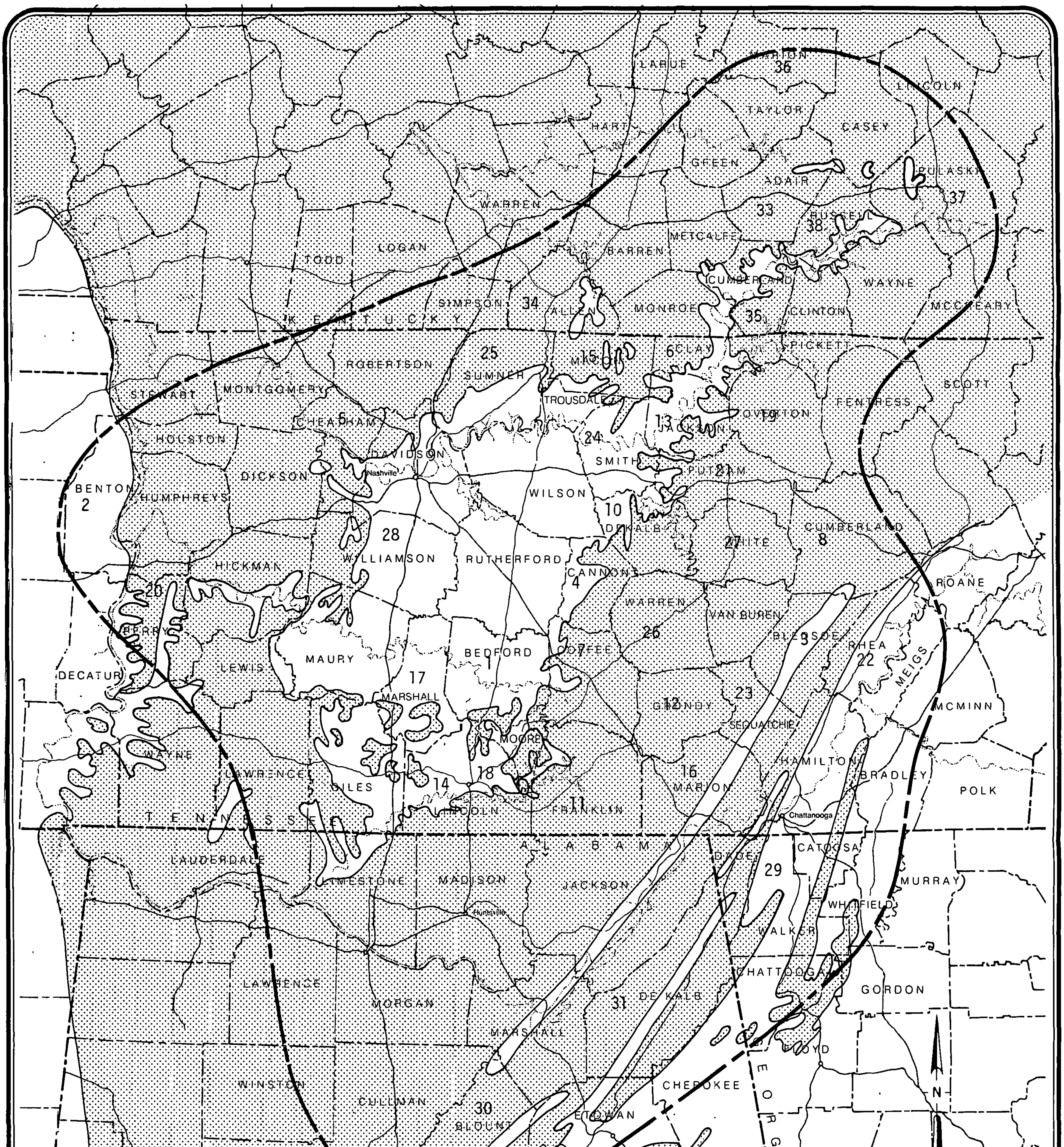
should be undertaken in one or more of the other likely areas. The cost of such drilling will be small in terms of the useful knowledge gained for an actual mining operation, and before any such mining is undertaken, drilling will have to be conducted whether the mine is to be in DeKalb County or elsewhere.

In view of these considerations it is worthwhile to examine briefly some of the other counties in Tennessee, scanty though the prospecting information may be.

A list of 26 holes and 101 outcrops with uranium assays in 30 other counties of Tennessee is given by Mutschler, et al. [1976]. This work also gives a table of eleven counties, excluding DeKalb, with number of "uranium observations" (100 observations in 11 counties). Using this information in conjunction with that provided by Hickman and Lynch [1967], the quadrangle maps and booklets of the Tennessee Department of Conservation, and the 420 sections listed in Stockdale and Klepser [1959], this author, after elimination of data considered untrustworthy, has prepared a list of outcrops and drill holes by county as shown in Table II-4 and summarized in Figure II-2. In this list the data presented by Mutschler, et al. [1976] is included for comparison, and data from DeKalb County is also included.

In comparing the data of Mutschler, et al. [1976] with that calculated by the author, the reader should bear in mind the following points: a) the present data is less complete due to lack of information; b) the present averages do not include data considered incomplete, faulty, or questionable; c) the present data include the overlying Maury, and in a few cases some Fort Payne, thus reducing the indicated uranium grade in all cases except Grundy County where the only drill hole shows 2 feet of Maury at 120 ppm [Mutschler, et al. 1976]; d) holes should be given greater credence than outcrops.

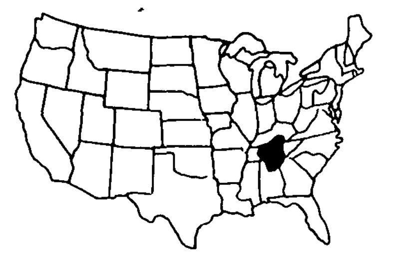
For purposes of discussion certain counties can be eliminated, keeping in mind that future investigation might alter this decision and that a part of a county might at some time in the future be mined for uranium



AVERAGE BY COUNTY OF GRADE AND THICKNESS OF GASSAWAY (&MAURY) IN HOLES AND OUTCROPS (adapted from Mutschler, et al. [1976])

<u>KEY</u>

County	# of Holes & Out-crops	Thick-ness(ft)	U (ppm)	County	# of Holes & Out-crops	Thick-ness(ft)	U (ppm)	County	# of Holes & Out-crops	Thick-ness(ft)	U (ppm)
1	1 otc	10	60	13	1 hle	11	52	26	2 hle	20	57
2	1 otc	19	43		3 otc	12	44	27	1 hle	14	54
3	1 hle	21	51	14	2 otc	7	67	28	1 otc	5	44
4	1 hle	17	47	15	3 hle	14	44	29	1 otc	13	31
	5 otc	14	54	16	1 hle	14	66	30	3 hle	26	46
5	2 otc	14	51	17	1 otc	6	56		1 otc	30	57
6	4 otc	14	55	18	1 hle	14	63	31	1 otc	7	41
7	2 hle	7	62	19	2 otc	13	46	32	1 otc	5	48
	3 otc	13	66	20	1 otc	9	39	33	1 otc	28	33
8	1 hle	24	62	21	1 hle	13	61	34	2 otc	16	50
9	3 hle	13	51		13 otc	16	49	35	3 otc	26	44
10	45 hle	14	55	22	2 otc	22	65	36	1 otc	32	37
	13 otc	14	52	23	1 hle	18	60	37	2 otc	40	37
11	1 otc	11	38	24	1 otc	8	49	38	3 otc	30	45
12	1 hle	17	70	25	5 hle	12	47				



☐ Area in which Chattanooga Shale is generally absent

☐ (dotted) Area in which Chattanooga Shale is generally present

FIGURE II-2

along with parts of adjacent counties. Some counties lie largely within the Nashville Basin or in other areas with little underlying Chattanooga Shale, but assays of outcrop samples are available because of the presence of outliers of Chattanooga. These counties, which include Bedford, Benton, Marshall, Moore, and Smith, could scarcely be producers of uranium from the Chattanooga. With thousands of square miles of central Tennessee underlain by flat-lying Chattanooga Shale, consideration of mining folded, faulted, and steep-dipping shale should presumably be postponed for years. On this basis it is possible to eliminate from present discussion the greater part of the following counties: Bledsoe, Rhea, and Sequatchie; also half of Marion County and part of Cumberland County have the Appalachian structures. Three counties, Clay, Davidson, and Jackson, are close to Nashville or the Cumberland River. This might or might not cause complications, but temporarily at least these three can be omitted from discussion. Low grade and/or inadequate thickness might well eliminate Franklin, Lincoln, Macon, Overton, Perry, Sumner, and Williamson. Cheatham County has a variety of the above factors weighing against it.

The foregoing decisions are obviously somewhat arbitrary except for the first group, particularly in view of the few assays available in each county. However, this does provide a starting point, leaving nine counties in Tennessee for immediate consideration as possible targets for exploration and development drilling. These nine are underlined in Table II-4. Van Buren is included because of its location even though no assay data are available. Cumberland County is also included although it might be eliminated by pillar requirements because of depth.

If the environmental problems in the Youngs Bend area of DeKalb County are no greater than those throughout the rest of the nine-county area, this location is the place to intitate operations unless mining problems are greater than elsewhere. If other parts of the nine-county area pose fewer serious problems with regard to environment and mining, the most favorable areas in these respects should be explored by drilling on some fairly broad spacing such as five or ten miles, followed by development drilling of the best area or areas on a one-mile or half-mile spacing.

TABLE II-4. URANIUM GRADES IN OUTCROPS AND DRILL HOLES IN SEVERAL TENNESSEE COUNTIES

County	No. of Holes & Outcrops	Thick-ness ft	Grade of U [a] ppm	No. of Sections	Thick-ness ft	Grade of U [b] ppm	REMARKS
Bedford				1 outcr	10	60	Few outliers only
Benton				1 outcr	19	43	Few outliers only
Bledsoe				1 hole	21	51	Folded structures 2 outcrops same grade as hole
Cannon	14	13	59	1 hole	16.5	47	
				5 outcr	14	54	
Cheatham				2 outcr	14	51	River, city, etc.
Clay	4	17	52	4 outcr	14	55	Cumberland River
Coffee	9	13	63	2 holes	7	62	
				3 outcr	13	66	
Cumberland				1 hole	24	62	1500'-2000' overburden above Chattanooga
Davidson	10	11	55	3 holes	13	51	Near Nashville
DeKalb	78	15	60	45 holes	14	55	
				13 outcr	13.5	52	
Franklin				1 outcr	11	38	
Grundy				1 hole	17	70	Hi-grade Maury (?)
Jackson	13	16	48	1 hole	11	52	Cumberland River
				3 outcr	12	44	
Lincoln				2 outcr	7	67	Southern third only
Macon	13	15	52	3 holes	14	44	
Marion				1 hole	14	66	E. half: folded struc.
Marshall				1 outcr	6	56	Few outliers only
Moore				1 hole	14	63	Few outliers only (also 2 outcr - 9' 56 ppm)
Overton				2 outcr	13	46	
Perry				1 outcr	9	39	
Putnam	11	17	53	1 hole	13	61	
				13 outcr	16	49	
Rhea				2 outcr	22	65	Folded structure
Sequatchie				1 hole	18	60	SE half of county folded
Smith	4	14	49	1 outcr	8	49	Few outliers only
Sumner	11	11.5	53	5 holes	12	47	NW half of county only
Van Buren							No assay info. available
Warren	6	15	60	2 holes	20	57	
White	5	15.5	54	1 hole	14	54	
Williamson				1 outcr	5	44	W. 1/3 of county only

[a] Calculated by Mutschler, et al. [1976]
[b] Calculated by Mountain States

Any drilling program undertaken in the future should include assaying for oil, P_2O_5, thorium, and possibly other elements at shorter intervals throughout the Maury and Chattanooga.

The timing of the drilling would depend upon general plans and the market price and requirements for uranium and oil. Aside from the timing there can be little question as to the need for either a one-stage development drilling program if DeKalb County is the indicated area, or a two-stage drilling program if DeKalb County is not the indicated area.

At the present state of knowledge many experts may postulate that 1) DeKalb County has the best grade in the nine-county area, 2) in the Cumberland Plateau region, the Chattanooga shale beds are too deeply buried for economical underground mining, and 3) the hard-scrabble soil produced by the Fort Payne near the edge of the Eastern Highland Rim makes for fewer good farms and fewer environmental problems near the Rim. However, these are generalizations which should not be relied upon in making the final decision. If there are problems with the lake in the Youngs Bend area, uranium reserves should be developed elsewhere. Lakes, rivers, wells, farms, cities, and houses will probably be crucial deciding factors in choice of area within the large zone of generally favorable grade, thickness, depth, and attitude of the Chattanooga Shale.

POSSIBLE URANIUM RESOURCES IN ADJOINING STATES

There are large areas of uraniferous Devonian shale in Alabama, Kentucky, and elsewhere. To determine whether one or more specific areas present a better target than the Eastern Highland Rim of central Tennessee poses a problem well beyond the scope of the present investigation.

In Alabama, along the southwest extension of the Sequatchie-Walden structure, there is a high-grade show on Little Ridge near Head springs in DeKalb County (Alabama). For a thickness of approximately 10 feet there is a 10 foot diameter area where auger holes show about 0.17 percent uranium. Outside this small spot, the normal grade of uranium

($\pm$ 1/35th the grade in the spot) is found in auger holes. William Hardeman (personal communication) believes this anomalous high-grade to be due to secondary enrichment along the shale bed which dips about 30° at this hot spot. He believes this spectacular enrichment is much less likely to occur where the shale is flat-lying, and he says that the great length of strike of this shale along Little Ridge makes eventual prospecting for other hot spots worthwhile. Hardeman has also prospected another richer hot spot in Tennessee, even more restricted in area. He points out that most of the published literature deals with the normal 30 - 70 ppm shale, and almost none deals with these high-grade anomalies. For purposes of the present discussion such anomalous hot spots are a side issue; the few other samples available in Alabama indicate lower grade than the Eastern Highland Rim (Figure I-2).

There is one reported low-grade outcrop in Georgia in the data at hand (Figure I-2).

This figure also shows 12 outcrops in Kentucky averaging 28 feet thick and 41.5 ppm in uranium. It is well known that Kentucky, Ohio, and West Virginia are underlain by thicknesses of shale greater than those in central Tennessee, but of lower grades. If 30 feet or more of shale averaging close to 40 ppm is a better producer than 15 feet of shale averaging close to 60 ppm, Kentucky and Ohio should be better producers than Tennessee. Aside from environment, the choice between the two general areas should be based upon mining costs and metallurgical considerations.

RECAPITULATION

An area of about three thousand square miles, comprising roughly nine counties along the Eastern Highland Rim of central Tennessee, is underlain by a flat bed of Chattanooga Shale, of which the upper (Gassaway) member is about 14-1/2 feet thick and assays 50 to 60 ppm uranium (59 to 70.8 ppm U_3O_8). Within this large area a smaller area of some 18 square miles in DeKalb County has been proven up by approximately 30 diamond drill holes averaging about 55 ppm U (64.86 ppm U_3O_8) for a thickness of

16-1/2 feet; this average includes the overlying Maury claystone as part of the ore section because the one to four-foot Maury, assaying about 14 ppm U, is expected to come in on the ore during mining. No other part of the nine-county area has holes at sufficiently close spacing to indicate whether the proven grade of any similar small area will eventually be 50 ppm, 55 ppm, or 60 ppm U (including the Maury).

It is not certain that the 18-square mile area in DeKalb County is the best 18 square miles in the entire 3,000, nor is it likely to be the only such area running as high as 55 ppm U. Over one-third of all the holes drilled are situated in this 18-square mile area, an area six tenths of one percent of the 3,000 square miles. The cost of further drilling to prove up more reserves in DeKalb County or to prove up other areas is small in relation to the investment required to prepare any block of ground for mining and processing uranium at a significant daily rate.

Environmental considerations and mining costs should dictate whether the eventual mine is located in DeKalb County, or elsewhere in the nine-county area. The choice between the better-grade shale of central Tennessee and the thicker, lower-grade shale of Kentucky (where open-pit mining might be possible), or other shales elsewhere, should depend upon extensive metallurgical work and extensive calculations of mining costs in conjunction with environmental investigation.

SECTION III
MINING

A complete mining plan for the Chattanooga Shale in Tennessee, prepared by the Cleveland-Cliffs Iron Company, is presented in Appendix I. The following is a summarization of the mining and backfilling techniques described by that study, as well as a summary of capital expense requirements and operating costs.

PRODUCTION VOLUME

There will be a capability to deliver to the beneficiation process 100,000 tons each day. To meet these requirements three essentially identical mines are needed in the complex, each producing 36,000 tons per day for a maximum total of 108,000 tons. Excess tonnage, when produced, will be stockpiled for emergency mill feed. Most of the following descriptions refer to a single mine but apply to each of the three mines.

MINING SYSTEM PARAMETERS

A room and pillar mining system is contemplated having openings 32 feet wide and 16 feet high with access to the shale from the surface through slopes or inclined adits. Each mine will be worked in a rectangular area 4.6 miles in the long dimension, down dip, and three miles in the short dimension, on strike. This mode has been chosen to maximize capability for backfilling 70 percent of the tailings.

There will be six active working panels in each mine with appropriate development crews, each working 20 shifts per week - four crews, five days per week, each area. The basic panel crew will consist of 10 men and a foreman, and will produce 4.2 rounds per shift, or 1800 tons. Average productivity in tons per man shift for all mine employees is expected to be 60 tons. The extraction ratio will be 73 percent in-panel, 61 percent overall. Employment for one mine will be 724 people classified as hourly paid and 78 salaried personnel for a total of 802.

Each of the three mines of the complex will be a separate entity with its own complement of machinery and workers. A manager of mines and a common engineering and administrative staff will serve the whole complex; otherwise each mine will be a separate unit operating independently of the others. The three-mine complex will employ 2,172 hourly personnel, 234 salaried personnel, and 33 engineering and managerial staff common to all three mines.

EQUIPMENT AND METHODS

Each operating mining area or panel will be equipped with similar equipment. The shale mining faces will be drilled with two articulated rubber-tired drill jumbos, each equipped with two hydraulic powered drills set up for one-man operation. These will be capable of drilling the entire round of 28 two-inch diameter holes from only one set-up to a depth sufficient to advance the face 12 feet with each round.

Drill holes will be primed with high strength primers and an electric blasting cap. The holes will be pneumatically loaded with a mixture of ammonium nitrate and fuel oil (AN/FO). AN/FO prills will be blown into the holes with a hand-held lance connected to a mobile pressure vessel equipped with an elevating platform for charging the upper holes. Two set-ups are required for each round and two men are required for this operation. Blasting will be carried out during shift changes.

The broken shale, after blasting, will be picked up and transported with eight-cubic yard load-haul-dump (LHD) units powered by air-cooled diesel engines to feeder-breaker units at the conveyor belt. It is expected that bucket capacity will be 7.56 tons of shale. Maximum one-way haulage distance will be limited to 800 feet with the average distance computed to be 500 feet.

Upon completion of the shale loading (mucking) portion of the mining cycle a mechanical scaling unit operated by one man will be used to scale down all loose material from the face, ribs, and roof, ensuring a safe work place.

Six-foot long roof bolts will be systematically installed by two drill jumbos in the overhead "back" on a five-foot grid pattern of 16 bolts per round. The roof bolting rubber-tired jumbo designed for one-man operation will be equipped with a basket-type elevating platform on which are mounted two hydraulic drills. Two machine set-ups per machine will be required per round.

Three LHD units, each operated by one man, will carry blasted shale from the mining faces to a feeder-breaker in the central drift of each panel. The feeder-breaker is a special combination of a rotary rock breaker and conveyor loading hopper twice the size of the LHD bucket. Its function is to take the instantaneous discharge of the shale from the LHD bucket into the hopper and to feed the material through the crusher to reduce all material to minus 12-inch size. The shale is moved through the feeder-breaker onto the moving panel belt at a predetermined rate for uniform belt loading with minimum spillage.

SHALE TRANSPORTATION

All shale will be transported from the mine to the outside surface storage facility by conveyor belts. In the mine all of these belts will be supported on wire rope mounted on floor stands with carrying idlers and heavy duty troughing idlers on 5-foot centers and return idlers on 10-foot centers. Rope anchors will be installed every 300 feet. Conveyors will be of different widths depending upon duty, speed, and operating factors.

The panel belts, on which the shale is first loaded by the feeder-breaker units, will be 36 inches wide and will carry 700 tons per hour at a speed of 200 feet per minute. These belts will need to be extended from 400 feet to 1,200 feet in length as mining advances through the panel. These belts will discharge onto the crossbelts.

The crossbelts, located in the panel access entries, will collect the material from all the panels working in that area and carry it to the main line conveyor. The crossbelts will be capable of handling 1,100 tons per hour at speeds of 300 feet per minute with a width of 36 inches. Impact idlers and skirt boards will be installed to minimize spillage at points where panel belts discharge onto the crossbelts.

Main line conveyor belts will be installed in the central drift of the main entry system. These conveyors will receive the discharge of the crossbelts and discharge onto the main adit conveyor. The main line conveyor will be 48 inches wide and will be capable of carrying 2,200 tons per hour at a speed of 600 feet per minute.

The main adit conveyor handles essentially the same tonnage as the main line conveyor. It operates from the bottom of the slope of the main adit to the surface storage facility. However, it works against the 10 percent grade of the main adit.

MINE VENTILATION

The ventilation system is designed to furnish, at full production, 1,600,000 cfm of fresh air brought into the mine through the surface adits, split and circulated through the working areas and controlled by doors, overcasts, regulators, and other control devices similar to those used in gassy coal mines, and finally exhausted to two sets of bleeder entries which will surround the entire mine. Each of the two sets of bleeder entries will terminate at the bottom of one of two circular concrete-lined ventilation shafts, each 20 feet in diameter, located at the outer extremities of the mine area. One axial flow fan will be located on the surface at each shaft. Each fan will be capable of exhausting 800,000 cfm of return air.

Special attention to certain working practices will be necessary since the shale is combustible, and both methane and radon daughter concentrations could be present [Kissell 1976; Mutschler, et al. 1976].

MINE DRAINAGE

In order to accommodate the requirement for backfilling the maximum amount of tailings it is necessary to mine down-dip, thus eliminating any possibility of natural drainage of water. From best available information the water inflow is expected to be 5,000 gallons per minute. Consequently, a four-inch pipe manifold system, roof mounted, will be installed and advanced for each panel to deliver water pumped from wet headings to a panel sump. Water from panel sumps will be pumped through eight-inch pipes to a centrally located sump equipped to store 1.2 million gallons of water. Pumps at this sump will pump the water vertically through a 14-inch borehole for surface discharge. The water is expected to be of sufficiently good quality not to require treatment for stream discharge.

MAINTENANCE AND SERVICE

A centralized service area will be established underground in order to provide facilities and services for maintenance and supply to the working areas. This will include repair bays to properly rebuild and maintain mining equipment, parts and material warehousing facilities, garaging facilities for the numerous personnel and material transporters, raw water for dust control, AN/FO bulk carrier and protective magazine, detonator magazine and special carriers, diesel fuel supply, and lubricating oils.

Specially trained crews with specialized equipment will be used to extend and move conveyor belts, pipe lines, and electric power facilities. The main 13.2 KV power sub-station will be in the service area and will supply the mine areas at 4,160 volts. The main pumps, crushers, and conveyor drives will operate at this voltage. Panel and section power centers will supply power at reduced voltages for face equipment, auxiliary fans, lighting, etc.

The reason-for-being for the service facilities is to ensure maximum availability of the mechanized equipment through efficient maintenance and service practices. The basic first step in striving for economic feasibility in this large-volume, low-grade enterprise is the attainment of dependable low production costs [Ensign 1974].

MINING COSTS

Preliminary mining costs estimates are presented in Table III-1 and are based upon engineering studies performed by the mining staff and quotes from major equipment manufacturers. All costs are based upon December 1977 dollars. A 2.2 year preproduction period followed by a 20-year productive life has been assumed.

TABLE III-1

COST SUMMARY FOR 3-MINE COMPLEX

A.	CAPITAL EXPENSE:		
	1. Preproduction Capital Requirements (Including Development Mining Costs)		$117,983,000
	2. Deferred Capital		
	Years 2-10		91,500,000
	Years 11-20		91,525,000
	3. Total Capital Requirements - Mining		301,008,000
	4. Capital Expense - Backfilling		54,558,000
	TOTAL CAPITAL REQUIREMENTS		$355,566,000
B.	OPERATING AND MAINTENANCE COSTS: (Dollars per Ton Mined)		
	1. Mining Costs [a]		
	Operating Labor	$0.8709	
	Operating Supplies	0.7839	
	Maintenance Labor	0.4042	
	Maintenance Supplies	0.2770	
	TOTAL COST PER TON MINED	$2.3360	
	2. Backfilling Costs		
	Operating Labor	$0.2100	
	Operating Supplies	0.1920	
	Maintenance Labor	0.0510	
	Maintenance Supplies	0.0310	
	TOTAL COST PER TON MINED	$0.4840	

[a] Does not include surface transportation of ore to processing facility.

SECTION IV

PROCESSING AND PRODUCTS

A processing technique has been devised to recover from the Chattanooga Shale a variety of products consisting of uranium, synthetic crude oil (syncrude), ammonia, and sulfur. In addition, if desirable, vanadium, cobalt, nickel, molybdenum and thorium may be recovered. This processing system brings together for the first time various segments of technology that provide a possible opportunity for low grade uranium shale to approach economic viability.

Discussed below is the Swedish Ranstad operation which, as the only uraniferous shale uranium recovery facility in the world, provides insight into technical possibilities for uranium recovery from such shales. Also discussed is an important shale oil recovery technology developed by the Institute of Gas Technology for eastern U.S. oil shales, which has been incorporated into the proposed process to provide a significant economic advantage to the combination of techniques for use with the Chattanooga Shale. Since the several desirable metal by-products present in relatively generous amounts in the Chattanooga Shale are in solution together with the uranium in this process, an opportunity is afforded to recover these materials and add their value to the economic base at very low cost.

The final segment of this section considers the net energy yield that may be derived from the Chattanooga Shale.

THE RANSTAD PROJECT

The only plant in the world now producing uranium from bituminous shale is at Ranstad in Sweden. A review of the Ranstad operation thus has special significance for the Chattanooga Shale study. This project was originally planned as a production facility with the potential to supply Sweden's eleven atomic reactors. Pilot operations were designed for an initial treatment rate of 1 million metric tons per year. However, delays in the reactor program resulted in a cutback of funds. Consequently the planned uranium production rate of 120 tons has never been attained and the plant has never run at more than 40 percent of capacity. The Ranstad plant has been operated since 1968 as a research facility with restricted tonnage and budget.

The recovery of uranium from 300 ppm U (350 ppm U_3O_8) shale is accomplished at Ranstad by sulfuric acid leaching of crushed ore in vats, followed by liquid ion exchange treatment of the solution. Overall recovery of the uranium from the shale is 79 percent. The plant features the application of mineral beneficiation (heavy media separation) to reject acid-consuming limestone prior to acid leaching. Possible future by-products include chemical fertilizer (ammonium sulfate), sodium sulfate, aluminum sulfate, molybdenum trioxide, in addition to vanadium products derived from the leach solutions and from the uranium ion exchange stripping and neutralization steps, supplemented by auxiliary recovery processes. Agricultural limestone is also a potential product. Leaching wastes are neutralized with limestone slurry.

PROJECT STATUS

The original Ranstad plant was built by AB Atomenergi, a government entity. Luossavaara-Kiirunavaara Aktiebolag (LKAB), a state-owned mining company, operated the plant beginning in 1975. Recently, a feasibility study for an expanded plant was prepared and studied by AB Atomenergi, the State Power Board, and LKAB. However, the municipalities of Skovde and Falkoping turned down any expansion of the Ranstad operation and recommended only continuance of small-scale research operations. LKAB considers subsidies by the government to be necessary to such continuance. Large-scale uranium mining and processing will have to be conducted on other occurrences of this uranium-bearing shale.

Most recently it was announced that Boliden Aktiebolag has joined with LKAB in a joint effort to conduct prospecting, research, and development of the Swedish aluminum shale resources. The consortium, Aktiebolaget Svensk Alunskifferutveckling (ASA), will seek the goal of fullest possible extraction of all mineral and chemical values from the shale [Mining Engineering 1977]. A report on the failure of the plans to expand Ranstad appeared recently in a technical journal [Engineering and Mining Journal 1977].

The highest grade of uranium in Swedish shales is found near and underlying Billingen Mountain near the towns of Skovde and Falkoping (Figure IV-1). These shales average 300 ppm uranium (0.03 percent) or the equivalent of 350 ppm U_3O_8. The shale occurs in a flat-lying deposit about 4 meters (12 feet) thick under an average of 25 feet of overburden. At Ranstad, the shale is within open pit distance of the surface and underlies good Swedish farmland. Initial operations were started on this limited strippable ore because of the relative accessibility and moderate mining cost. Expansion of the Ranstad operation would require planning for underground mining beneath Billingen Mountain.

Total content of the shale in the Billingen area is approximately 1 million metric tons of uranium metal. Thus it is western Europe's largest known deposit and represents about 16 percent of the world's total uranium reserve known in 1967. Uranium resources readily recoverable from this deposit could provide as much as 300,000 metric tons (330,000 short tons). By comparison, the uranium contained in the Chattanooga shale has been estimated at 5.4 million metric tons (6 million short tons). Since the Chattanooga shale is only 1/6 the grade of the Swedish shale, greater quantities of rock must be handled.

SHALE CHARACTERISTICS

The Swedish uraniferous shales (Figures IV-2, IV-3, and IV-4) are upper Cambrian in age and generally occur in horizontal beds. In some localities geological conditions and erosion have placed the layer within open pit

GEOGRAPHIC LOCATION OF BILLINGEN MOUNTAIN IN SWEDEN

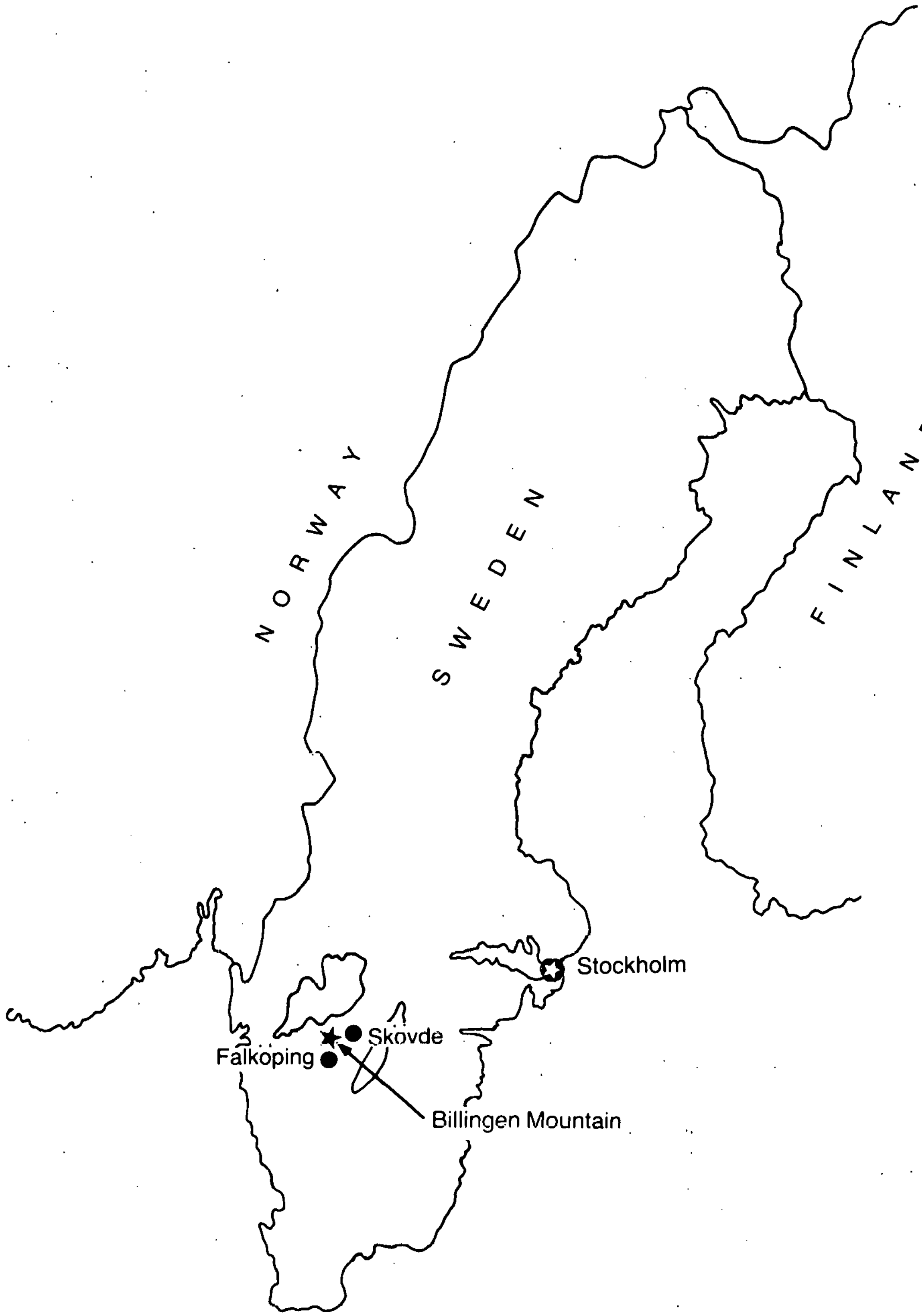


FIGURE IV-1

stripping distance of the surface; elsewhere it is buried under sufficient overburden to require higher cost underground mining. The shale contains up to 22 percent organic carbon and 13 percent pyrite, together with minor values of molybdenum, vanadium, and nickel. Existing studies have not considered the economic feasibility of processing these constituents of the shale. However, research is being conducted to evaluate extraction of the following products and by-products if a calcination step is included in the process scheme:

- Uranium
- Heat. The shale is 15.5% C and 2% H_2 and contains 1,800 kilocalories per kilogram (3,240 BTU per pound); about one-quarter that of good grade bituminous coal.
- Pyrite = Fe + S (from these, sulfuric acid and iron blast furnace feed may be produced)
- Molybdenum
- Vanadium
- Nickel
- Rare earths
- Alumina
- Building materials

Table IV-1 shows the content of the Ranstad shale in certain chemical elements compared to Swedish consumption and imports of these same elements. Additional by-products and co-products may result from this list. Table IV-2 indicates the percentage content of various substances found in uraniferous shale, not including oxygen bound to the metals.

A typical simplified analysis of the Swedish shale from Ranstad is presented in Table IV-3.

Figures IV-5 through IV-11 present the shale contents in terms of various elements as a function of depth below top of shale member.

OUTCROPS OF ALUMINIFEROUS SHALE IN SWEDEN

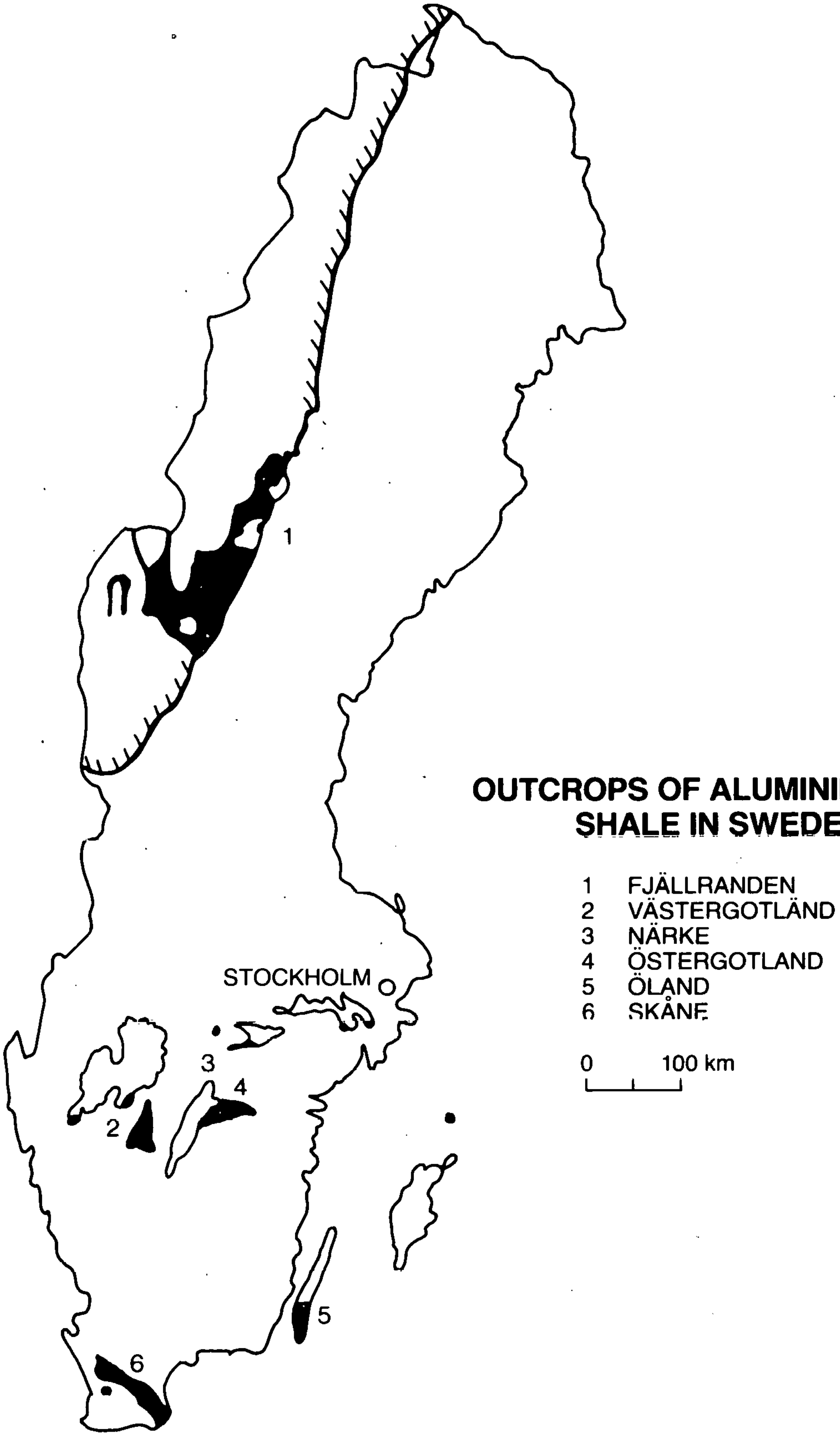
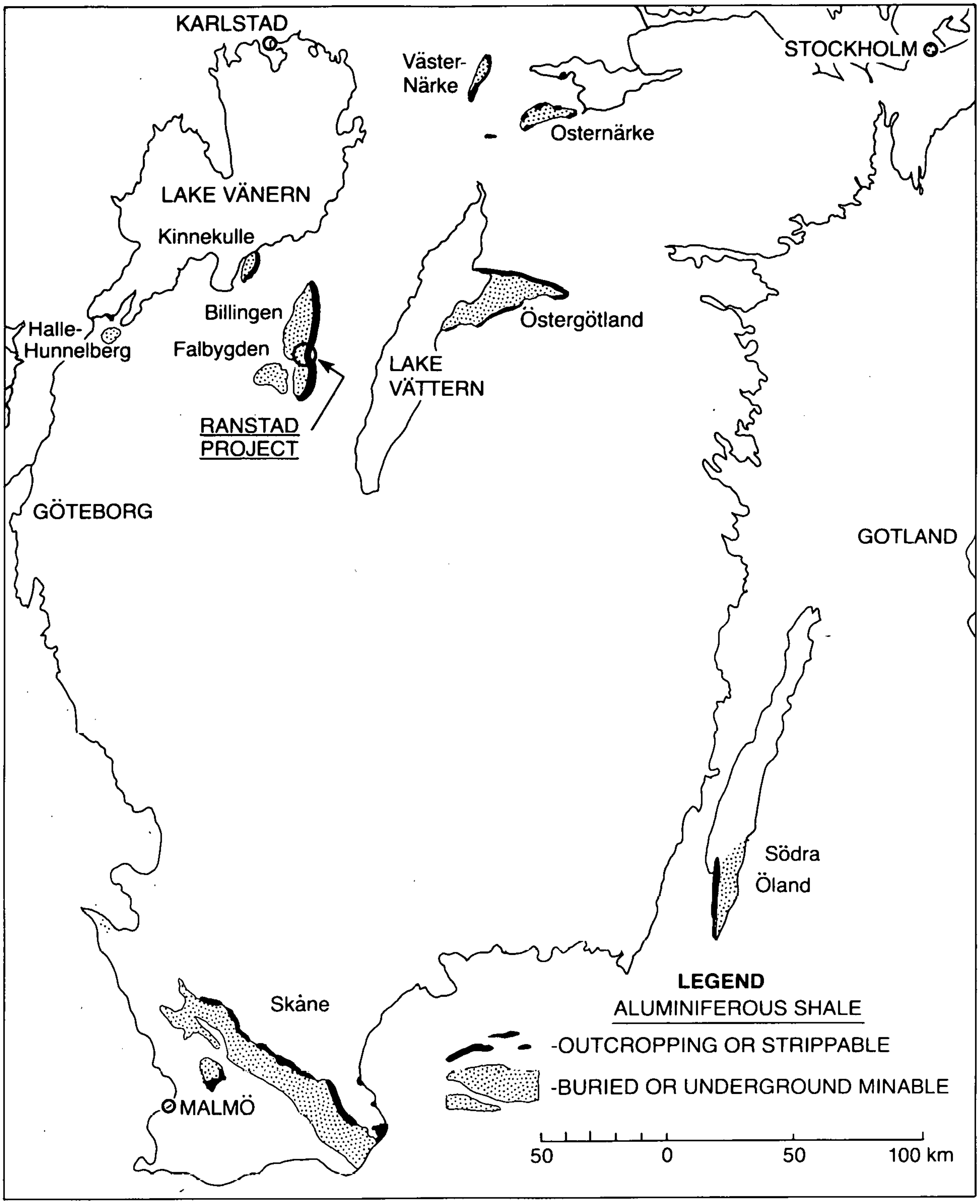


FIGURE IV-2



SOUTHERN SWEDISH OCCURRENCES OF ALUMINIFEROUS SHALE

FIGURE IV-3

SECTION THROUGH BILLINGEN

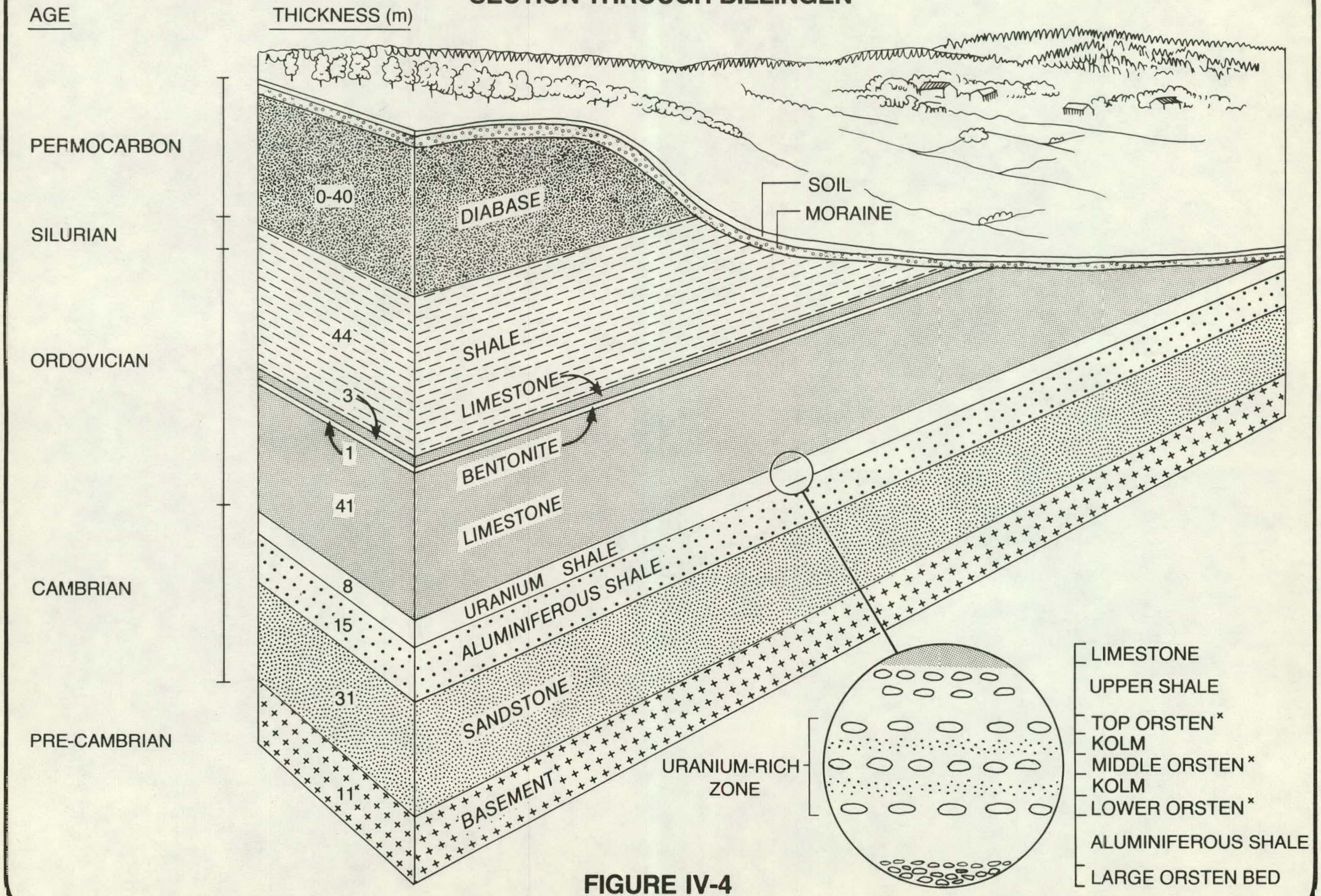


FIGURE IV-4

TABLE IV-1. COMPOSITION OF ALUMNIFEROUS SHALES AT RANSTAD, SWEDEN, AND SWEDISH CONSUMPTION AND IMPORT OF COMMODITIES CONTAINED IN THE SHALES

	Content of one million metric tons of Ranstad Shale [a] (metric tons)	Swedish Consumption 1973 (metric tons)	Swedish Imports 1973 (metric tons)
Aluminum	60,000	160,000	132,000
Potassium	35,000	120,000	120,000
Magnesium	4,000	8,000	8,000
Phosphorus	700	250,000	250,000
Sulfur	65,000	250,000	190,000
Vanadium	650	900	900
Molybdenum	300	4,000	4,000
Nickel	200	30,000	30,000
Uranium	270		

[a] Heating value of one million metric tons of the shale corresponds to about 180,000 metric tons of oil.

TABLE IV-2. PERCENTAGE CONTENT OF VARIOUS CONSTITUENTS IN THE URANIFEROUS SHALE, NOT INCLUDING OXYGEN BOUND TO METALS

Constituent	Percent	Constituent	Percent
U	0.030	Ni	0.02
Mo	0.034	Pb	0.0014
V	0.075	Ra^{226}	9.5×10^{-9}
Al	6.6	Sb	0.0005
Fe	6.0	Ti	0.38
K	4.0	Zn	0.013
Na	0.21	Rare Earths	0.041
Mg	0.49	C (org)	15.1
Ca	0.9	S (total)	7.0
As	0.0106	SiO_2	45
Cd	0.00022	CO_3	1.3
Cr	0.032	PO_4	0.25
Cu	0.011		
Hg	0.000031		
Mn	0.025		

TABLE IV-3. SHALE ANALYSIS

Element	Percentage
C	15.1
H	2
Al	6.6
K	4.0
Mg	0.49
P	0.07
S	7.0
V	0.065
Mo	0.03
Ni	0.02
U	0.03

GRAPH THROUGH ALUMINIFEROUS SHALE FORMATION, SOUTH BILLINGEN MOUNTAIN AREA

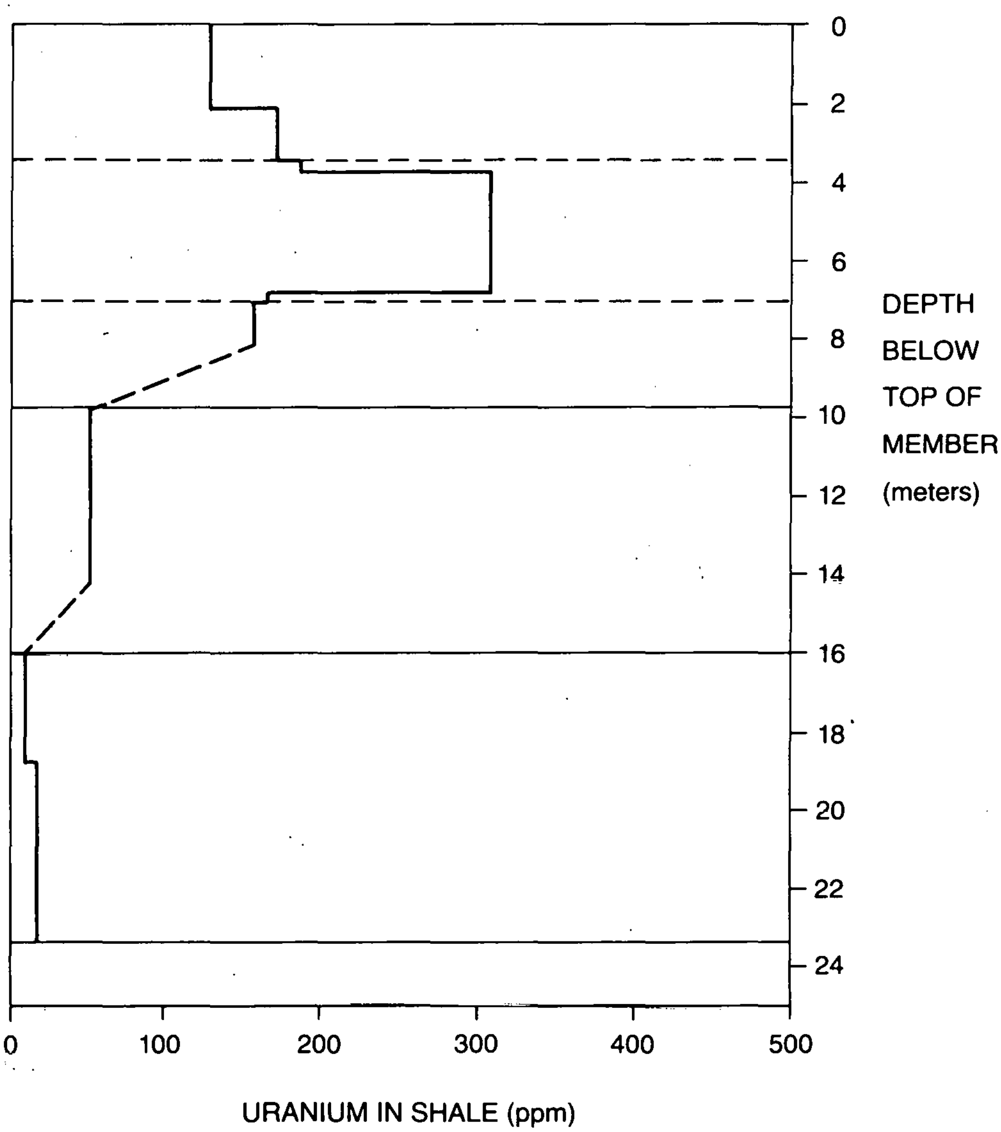


FIGURE IV-5

GRAPH THROUGH ALUMINIFEROUS SHALE FORMATION, SOUTH BILLINGEN MOUNTAIN AREA

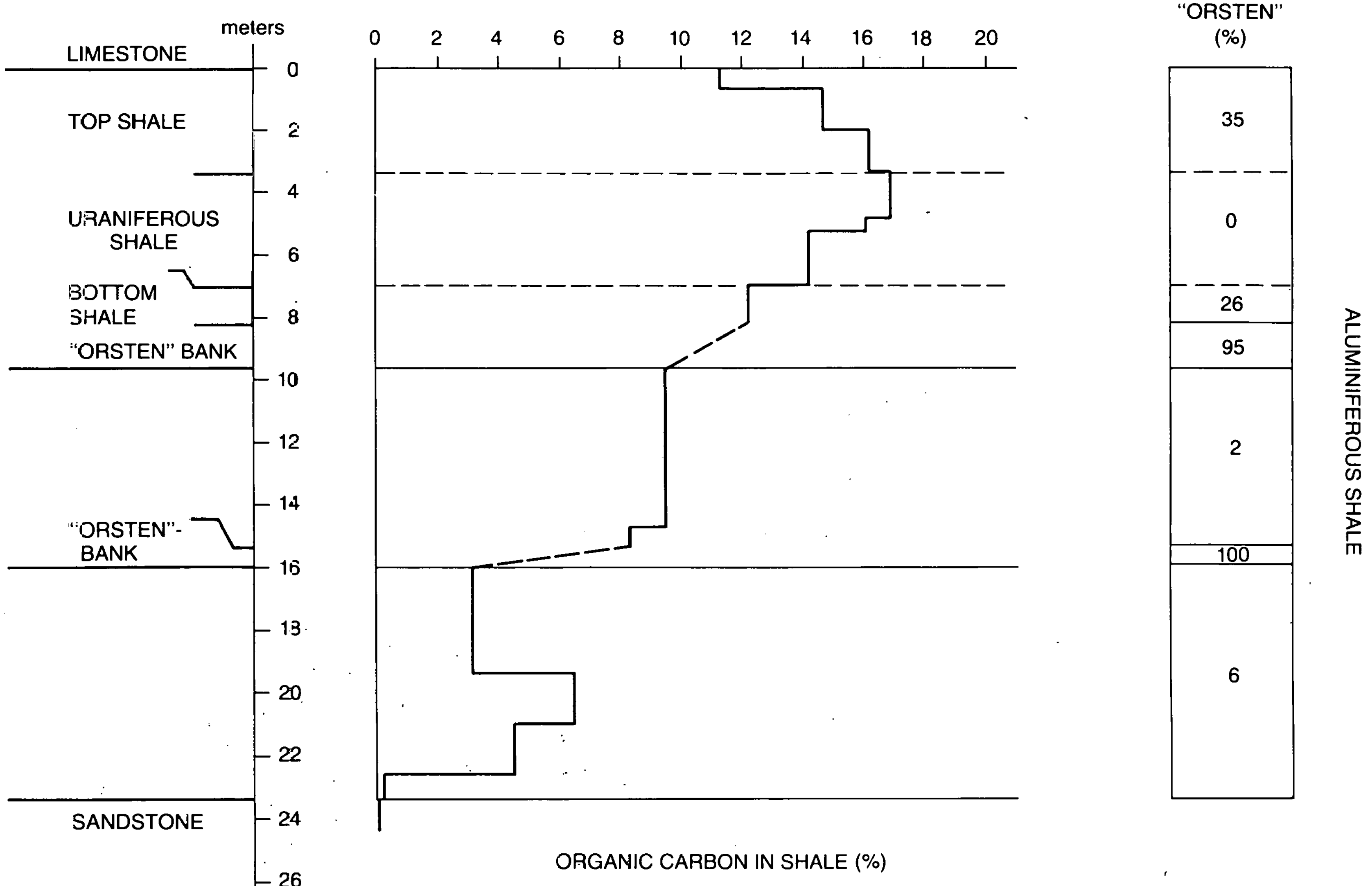


FIGURE IV-6

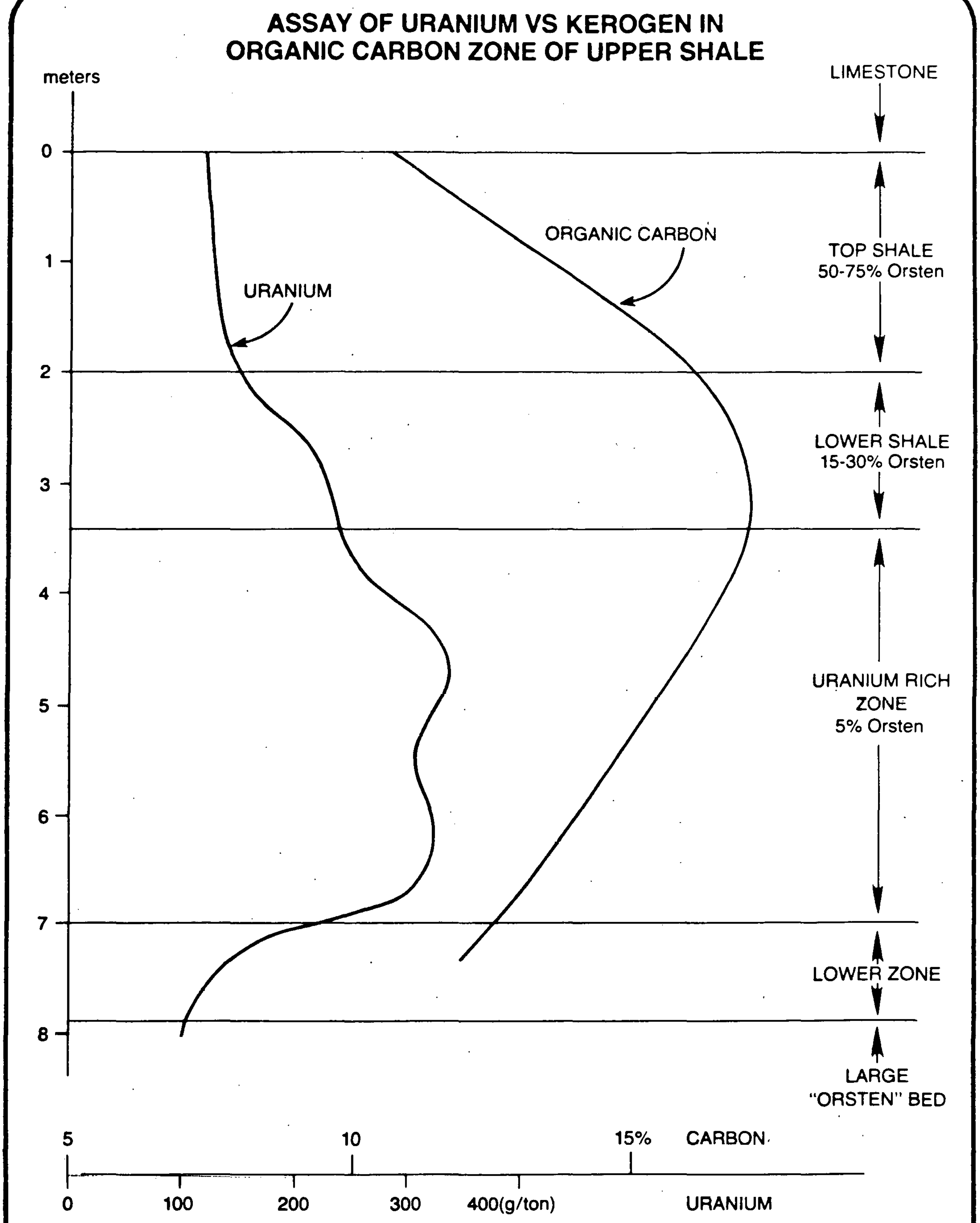

ASSAY OF URANIUM VS KEROGEN IN
ORGANIC CARBON ZONE OF UPPER SHALE
meters
LIMESTONE
0
1
2
3
4
5
6
7
8
ORGANIC CARBON
URANIUM
TOP SHALE
50-75% Orsten
LOWER SHALE
15-30% Orsten
URANIUM RICH
ZONE
5% Orsten
LOWER ZONE
LARGE
"ORSTEN" BED
5
10
15%
CARBON
0
100
200
300
400(g/ton)
URANIUM

FIGURE IV-7

GRAPH THROUGH ALUMINIFEROUS SHALE FORMATION, SOUTH BILLINGEN MOUNTAIN AREA

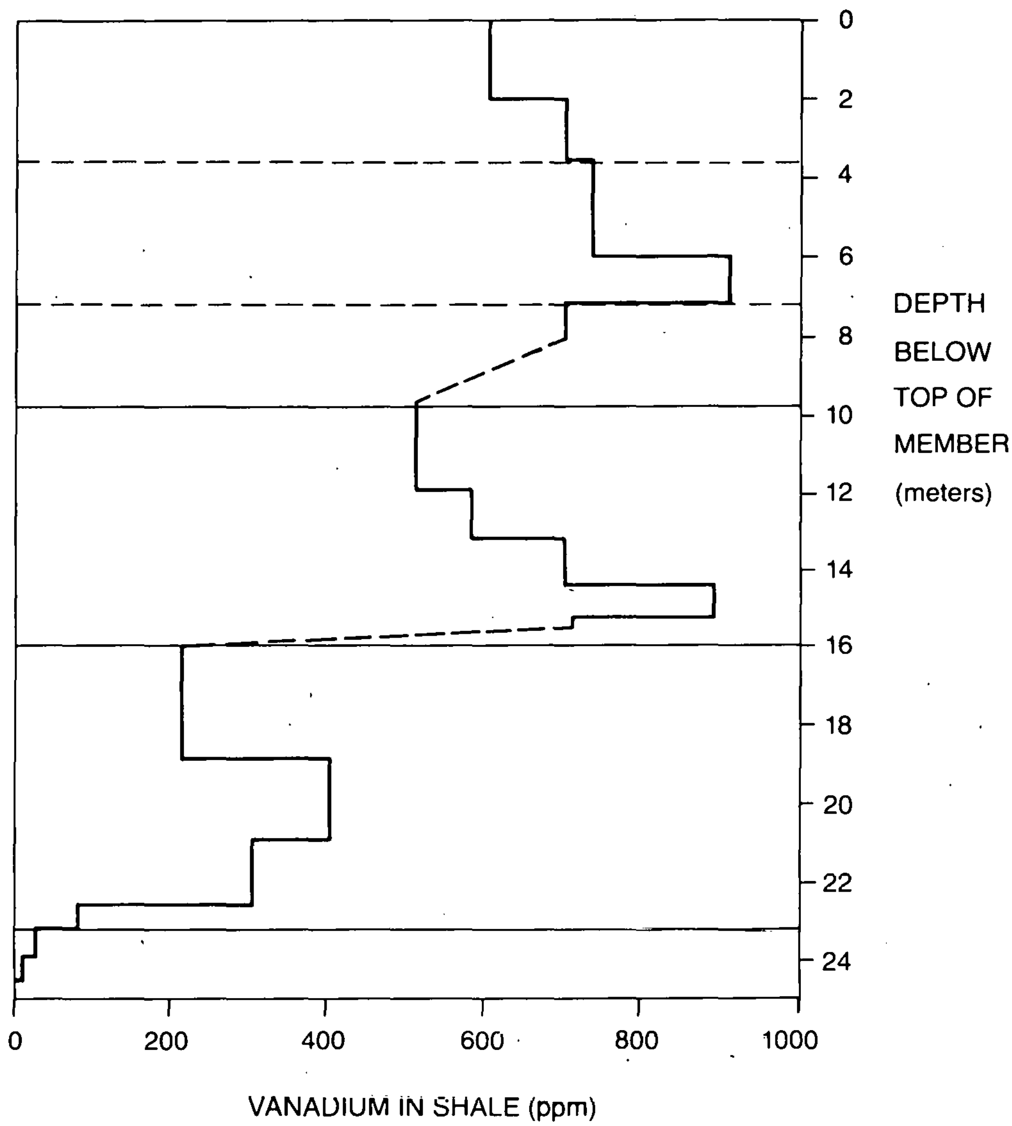


FIGURE IV-8

GRAPH THROUGH ALUMINIFEROUS SHALE FORMATION, SOUTH BILLINGEN MOUNTAIN AREA

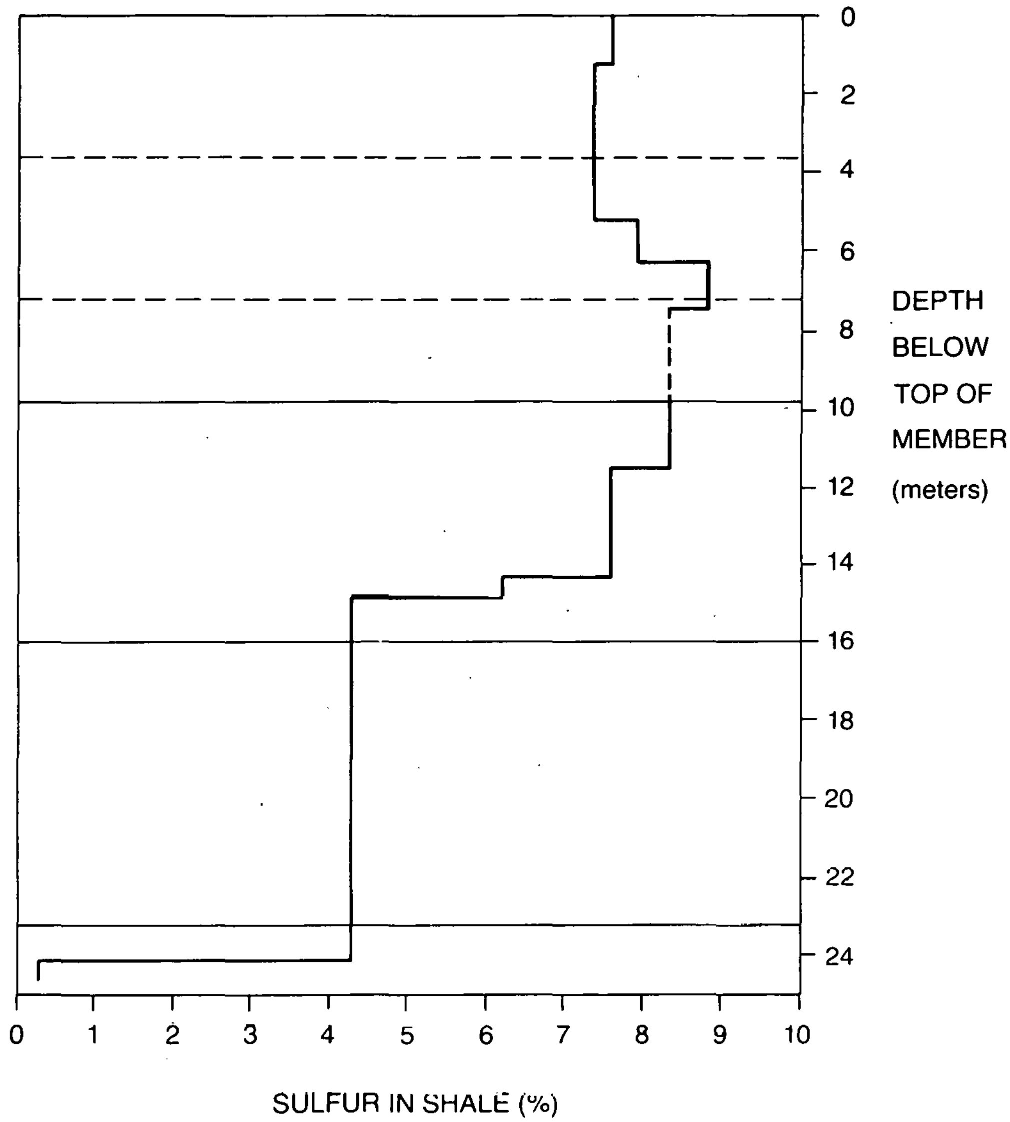


FIGURE IV-9

GRAPH THROUGH ALUMINIFEROUS SHALE FORMATION, SOUTH BILLINGEN MOUNTAIN AREA

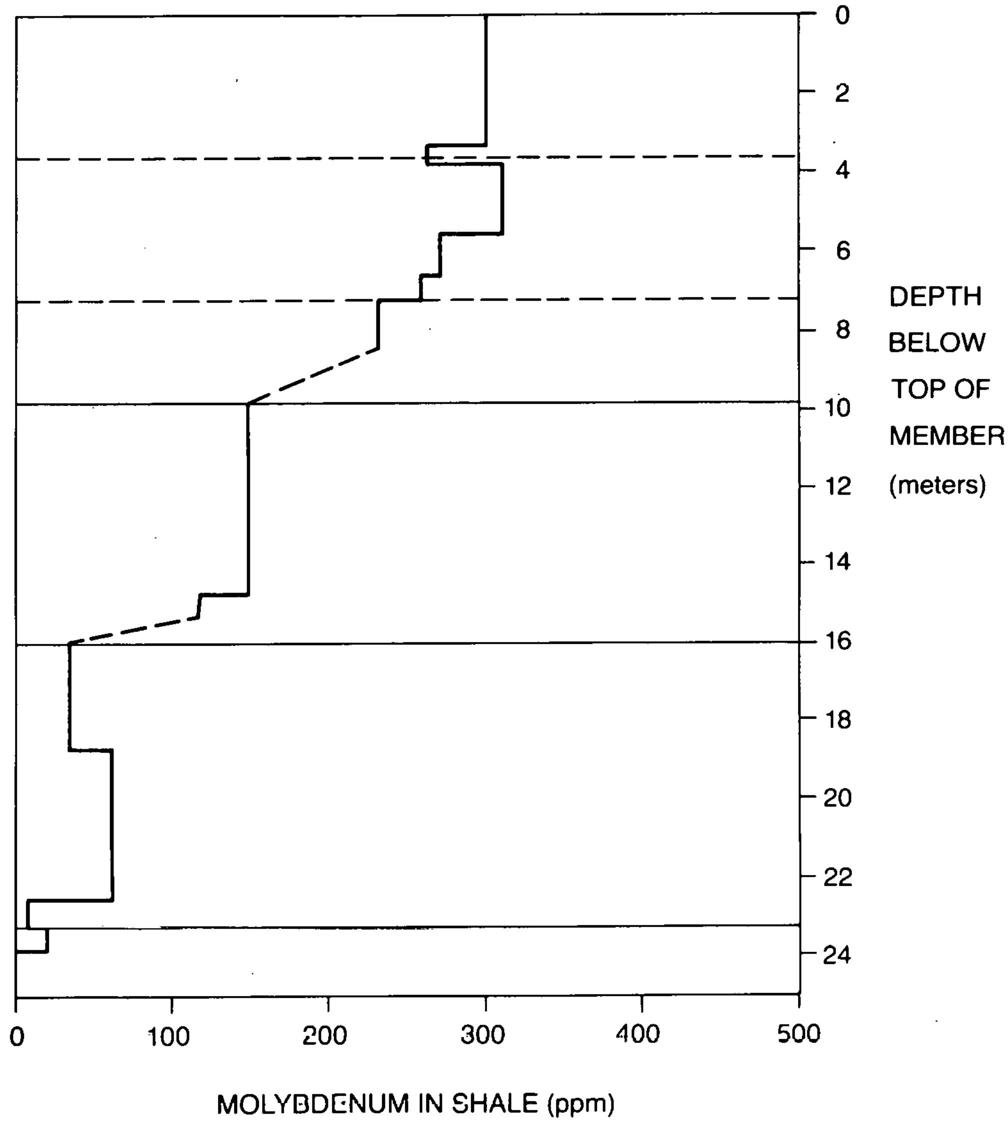


FIGURE IV-10

SECTION THROUGH ALUMINIFEROUS SHALE FORMATION

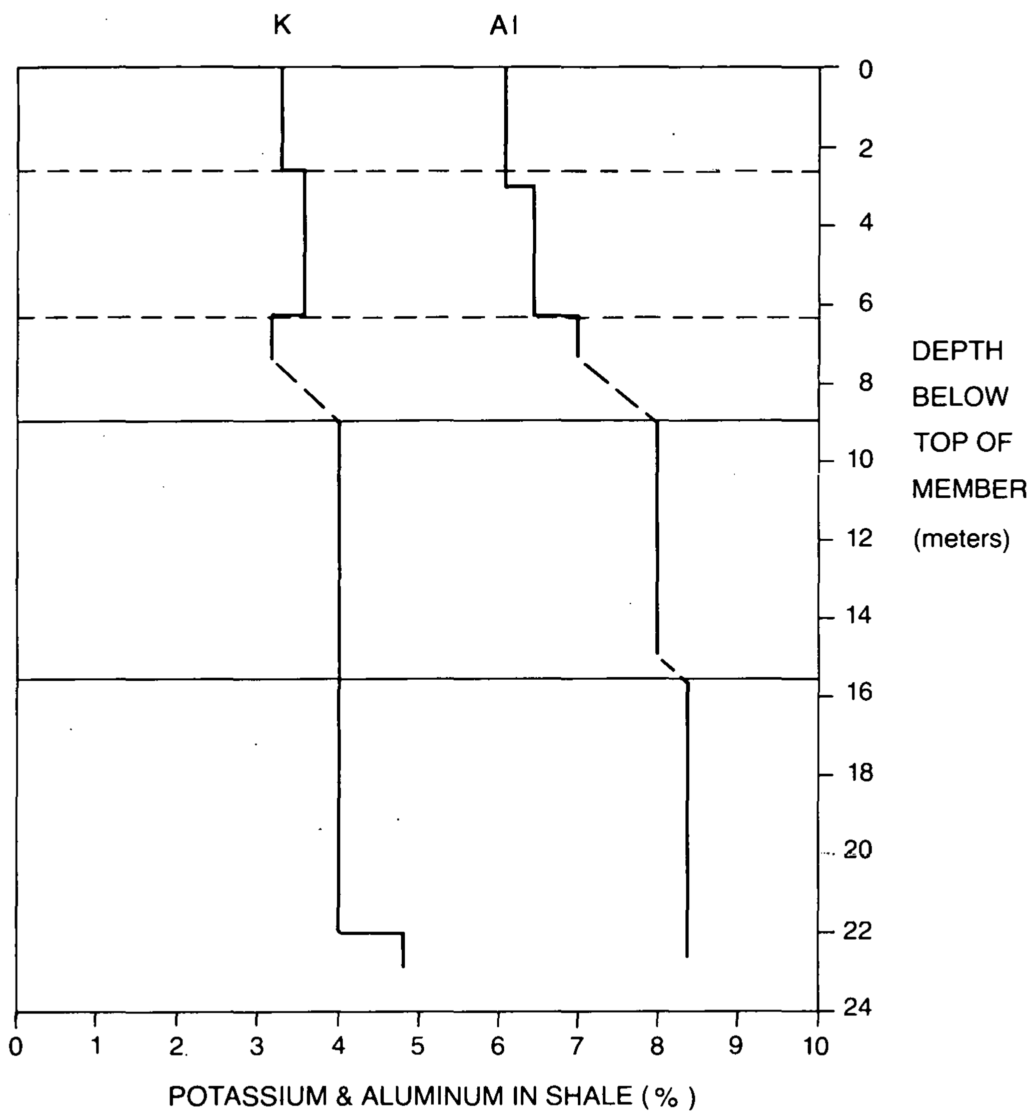


FIGURE IV-11

PROCESSING

The processing scheme at Ranstad is well adapted to the ore. The plant is well designed and solidly built.

The Ranstad processing scheme consists of open cut mining, dumping into an underground pocket onto an underground conveyor, primary crushing to about 350 mm (14 inches), and discharge into large storage silos across a screen where minus 6 mm (1/4 inch) is screened out and discarded. The oversize is divided into two sizes into two silos: minus 40 mm (1-1/2 inch) plus 6 mm (1/4 inch) and minus 350 mm (14 inch) plus 40 mm (1-1/2 inch). The larger size is crushed in impact crushers to 40 mm (1-1/2 inch). Dust is removed in the impact crusher dust system, pelletized with sulfuric acid, and added to the ore before leach. The other portion of the ore is subjected to heavy media separation. The separation of lime (originating in bituminous limestone inclusions, see Figure IV-4) in the magnetite heavy media circuit is effective. The ore heads average 6.7 percent CaO and the leach feed is reduced to about 1 percent CaO, with consequent savings in acid consumption.

The original design provided a large aging pad for natural bacterial action and oxidation as well as volatilization of methane gas. Actual operation of the plant proved that the aging did not improve uranium extraction as originally supposed, so its use was discontinued.

The ore, both coarse and agglomerated, goes to six leaching vats of 2000 tons capacity each for 5 days of percolation leaching followed by 1 day of washing. Leach solutions are warmed to 70°C. A total of four leaching solutions and two wash solutions are used counter-current to the ore. Overall average usage of leaching solution is 0.35 m^3 per day per metric ton of shale (83 gal per short ton). Acid consumption is 55 kg per metric ton (108 lb per short ton).

In 1974, a proposal was made to expand the operation to 6 million metric tons per year and the projection shown in Table IV-4 was calculated.

The capital cost of this expansion, if implemented, would have been $144 million at 1966 prices. As explained earlier, the plans for expansion were never approved.

Plans for recovery of uranium from solution have always included ion exchange or solvent extraction. The Eluex process was used for the original trial. This process provided an effective combination of both processes. However, polythionate resin poisoning proved to be a serious obstacle and later plant operation used only solvent extraction employing an amine extractant (General Mills-Alamine 336). The carbonate strip and caustic precipitation of sodium diuranate was retained.

Information regarding plant supplies and projected products, energy requirements, and process water demand and effluent quality is presented in Tables IV-5 through IV-9. Figures IV-12 through IV-20 present various general and detailed flowsheets of current and proposed operations at Ranstad. The proposed operations would have been the result of plant expansion to a treatment rate of 6 million metric tons per year.

Figures IV-21 and IV-22 present uranium extraction as a function of leaching time and temperature, respectively. Figure IV-23 presents details of tailings dam construction.

PRODUCTION COSTS

The original plant, constructed at a cost of $28 million at 1965 prices, had a projected uranium cost of $10-11 per kg uranium ($5.84 per lb U_3O_8) at a processing rate of 1 million metric tons of shale per year. These costs do not include amortization charges.

Current projections show that an expansion to a processing rate of 6 million metric tons per year would have a capital cost in 1978 dollars of $470 million and produce uranium at a cost of $30 per pound. This

TABLE IV-4. PROJECTED SCALE OF OPERATIONS - REPORT OF 1974

Ore Mined	6 Mt/year
Feed to Leaching	5.4 Mt/year
Feed Grade	300 g/ton
Recovery, Leaching	79 percent
Recovery, Solvent Extraction	99.7 percent
Production, Uranium	1,275 t/year
CONSUMPTION OF:	
Sulfuric Acid	0.3 Mt/year
Water	2.2 Mm^3/year
Steam	0.4 Mt/year
Power	160 GWh/year
Number of Employees	825

Mt = Million metric tons.
Mm^3 = Million cubic meters

TABLE IV-5. BASIC SUPPLIES FOR PLANT OPERATION

	Consumption Metric Tons per Year
Sulfur [a]	27,000
Caustic (NaOH)	250
Soda Ash (Na_2CO_3)	500
Ammonia (NH_4OH)	20
Kerosene	15
Amine (Alamine 336)	0.4
Dodecanol	0.3
Diesel Oil	3,500
Fuel/Heating Oil	10,000
Process Chemicals (as above)	800
Magnetite Media	400
Explosives	400

[a] The sulfur is transported in molten form. If spillage occurs, the sulfur solidifies and does not contaminate the environment. The sulfur is used to produce 81,000 metric tons of sulfuric acid per year for leaching uranium.

TABLE IV-6. PROJECTED PRODUCTS FROM RANSTAD

Product	Metric Tons per Year
Uranium (as sodium diuranate)	300
Molybdenum (as molybdic trioxide)	6
Chemical Fertilizers	7,000
Sodium Sulfate	700
Agricultural Lime	100,000
Alumina and vanadium products	45,000

TABLE IV-7. PROJECTED ENERGY DEMAND OF PLANT PROCESSING ONE MILLION METRIC TONS OF SHALE PER YEAR

Electrical Energy	70,000 kWh/year
Fuel/Heating Oil	Equivalent 1 - 115,000 kWh/year
Oil	Equivalent 2 - 40,000 kWh/year
Sulfur	Equivalent 3 - 61,000 kWh/year
Approximate Total	290,000 kWh/year

1. From 10,000 metric tons per year
2. From 3,500 metric tons per year
3. From 80,000 metric tons per year

TABLE IV-8. CALCULATED WATER DEMAND DURING PLANT OPERATION [a]

	Water Requirement m^3/d
Mineral Dressing	345
Leaching, Extraction	1,225
Neutralization, Evaporation	825
Steam Generation and Sulfuric Acid Production	535
Cooling Water	10,000
Development and Laboratory Activities	350

[a] Amount of water, averaged over a year, needed in production of uranium from 1.1 million metric tons of shale per year.

TABLE IV-9. CALCULATED WATER QUALITY IN TWO PLANT AREAS AND CORRESPONDING YEARLY DISCHARGES

Element	Water into Sandstone From Open Pit Mine Concentration g/l	(Flowrate = 4 m^3/d) Discharge metric tons per year	Water to Environment From Tailings Dam Concentration g/l	(Flowrate = 50 m^3/d) Discharge metric tons per year
Ca	570	0.8	570	10
SO_4	2,100	3	2,200	39
K	120	0.2	140	2.5
Mg	80	0.1	70	1.2
NH_4	20	0.03	16	0.3
Na	16	0.02	20	0.3
Mn	10	0.01	7	0.1
Mo	10	0.01	<0.1	<0.002
U	0.6	0.001	<0.01	<0.0002
Zn	0.5	0.0007	<0.1	<0.002
Cu	0.1	0.0001	0.05	0.001
Ni	0.3	0.0004	0.8	0.013
Cd	0.06	0.0001	0.1	0.002
Cr	0.02	0.00003	0.1	0.002
Pb	0.06	0.0001	0.1	0.002
As	0.06	0.0001	<0.02	<0.0003
Fe	1.2	0.002	0.8	0.03
Hg	<0.001	<0.000001	<0.001	<0.00002
Total Chemical Salts, metric tons/year		4.2		53
Portion of chemical salts consisting of gypsum		2.8		36

FLOW SHEET–
REPORT OF 1974

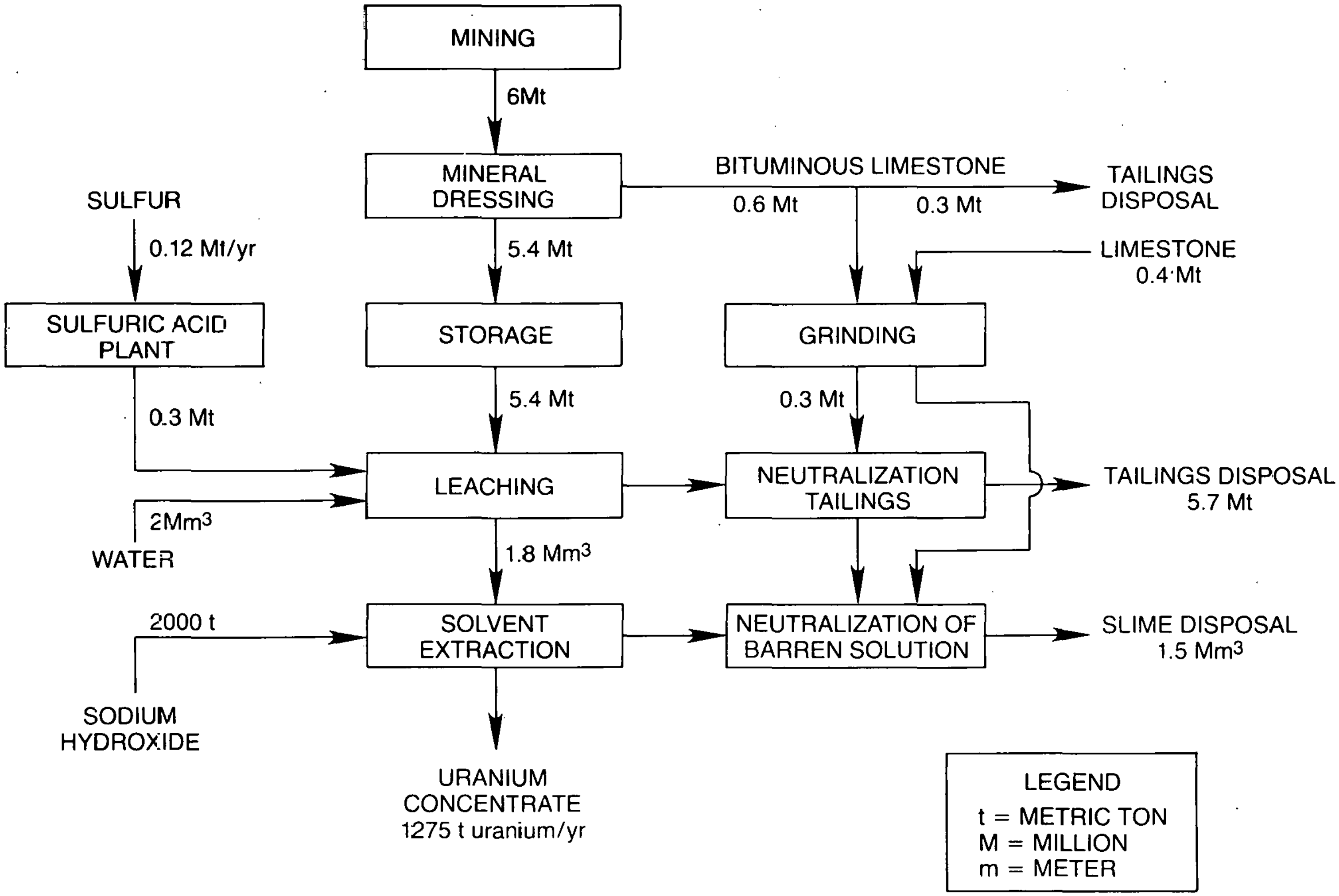


FIGURE IV-12

GENERAL PICTORIAL FLOWSHEET
ORIGINAL RANSTAD URANIUM PLANT

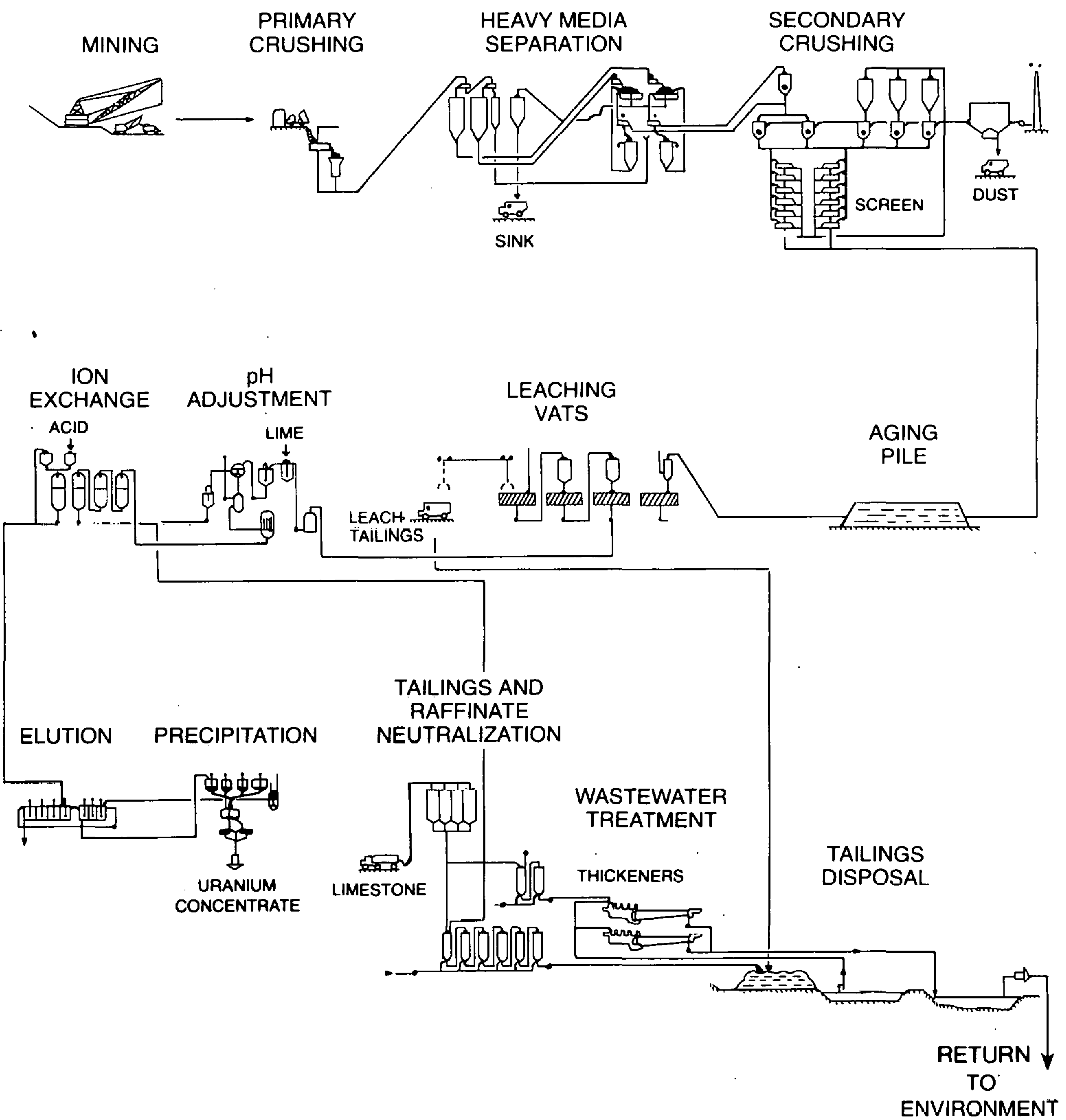


FIGURE IV-13

BLOCK DIAGRAM—UNIT OPERATIONS CURRENT PLANT

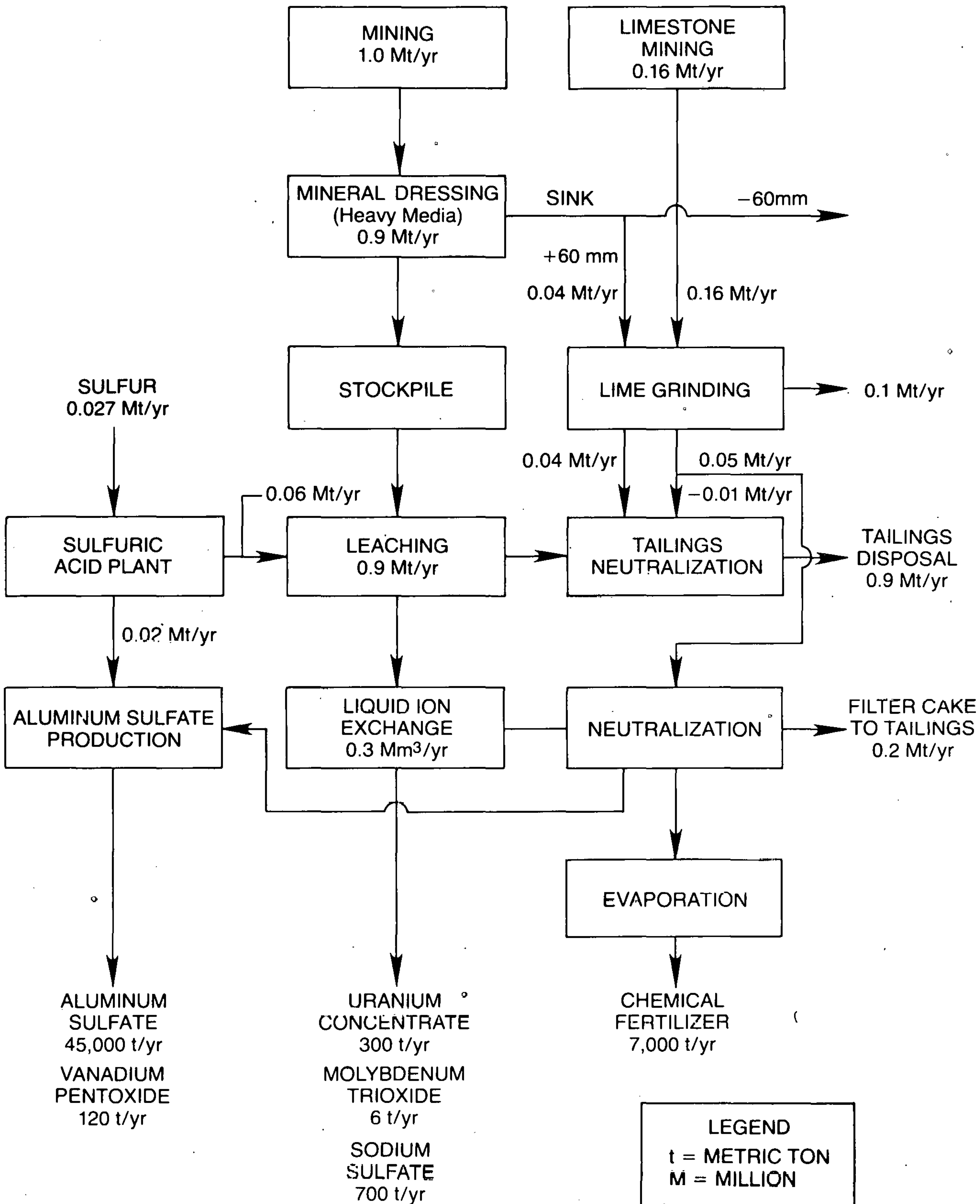


FIGURE IV-14

HEAVY MEDIA SEPARATION PLANT- DETAIL

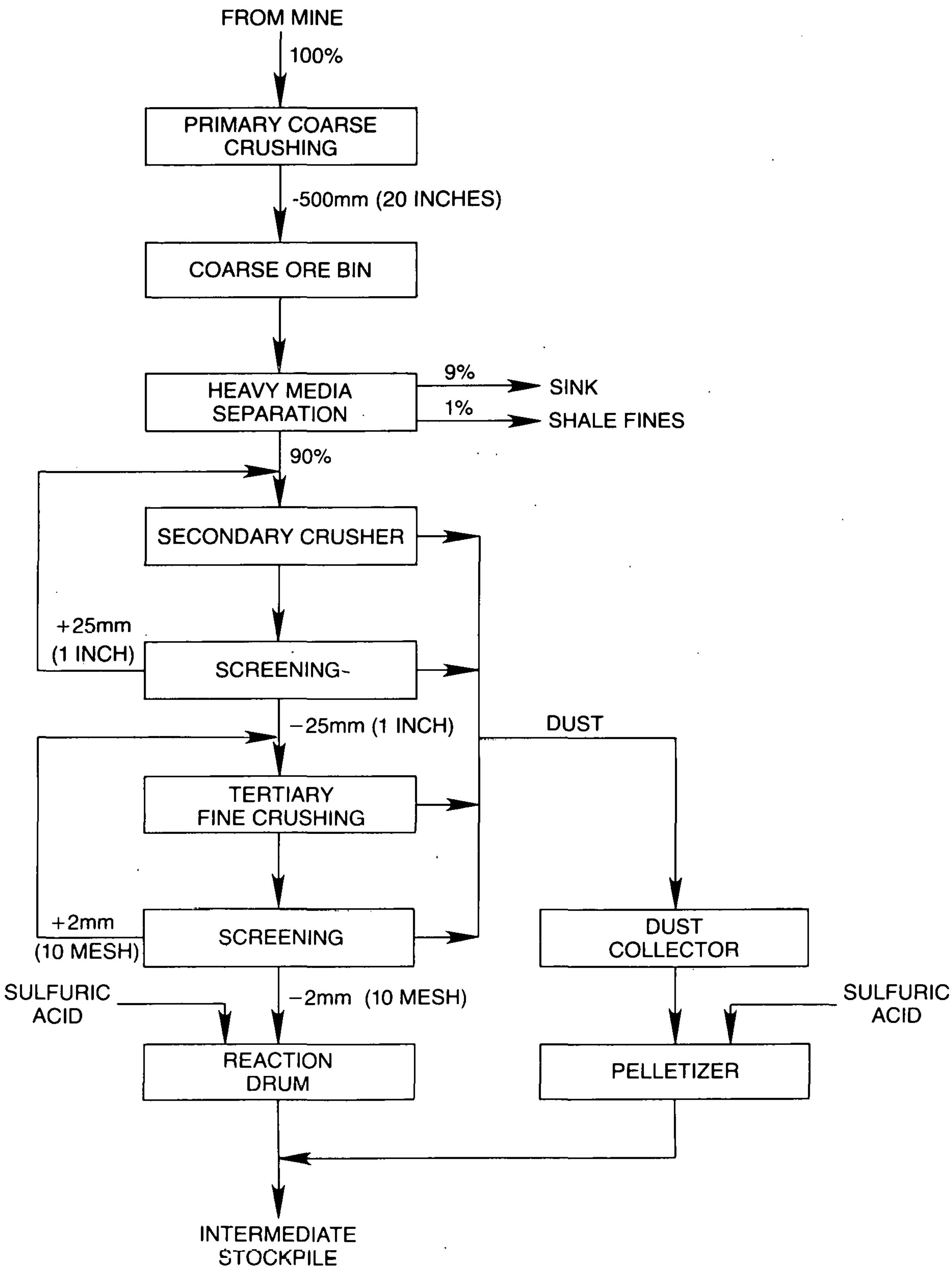


FIGURE IV-15

URANIUM RECOVERY FLOW SHEET-DETAIL

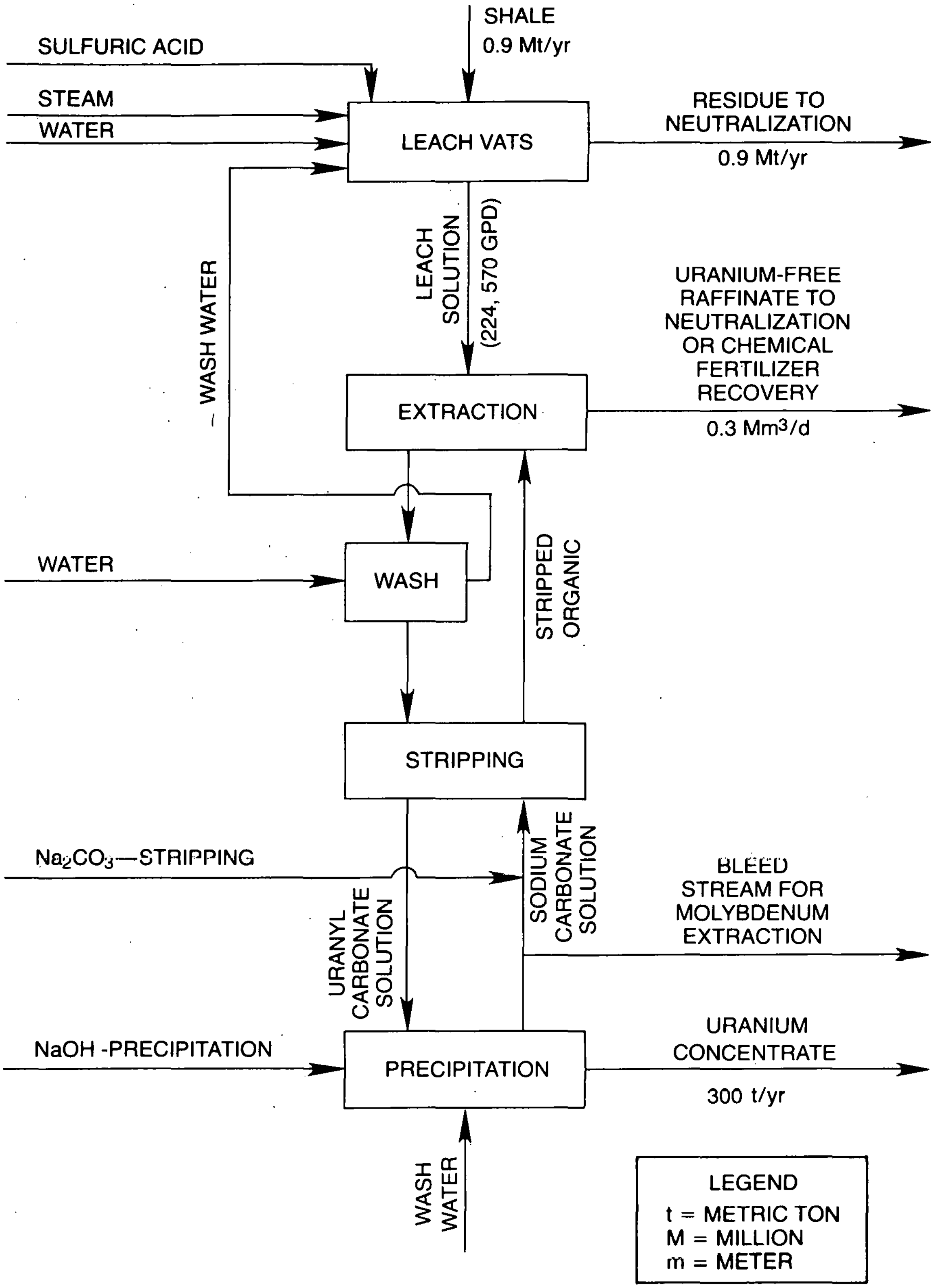


FIGURE IV-16

MOLYBDENUM AND SODIUM SULFATE RECOVERY FLOW SHEET-DETAIL

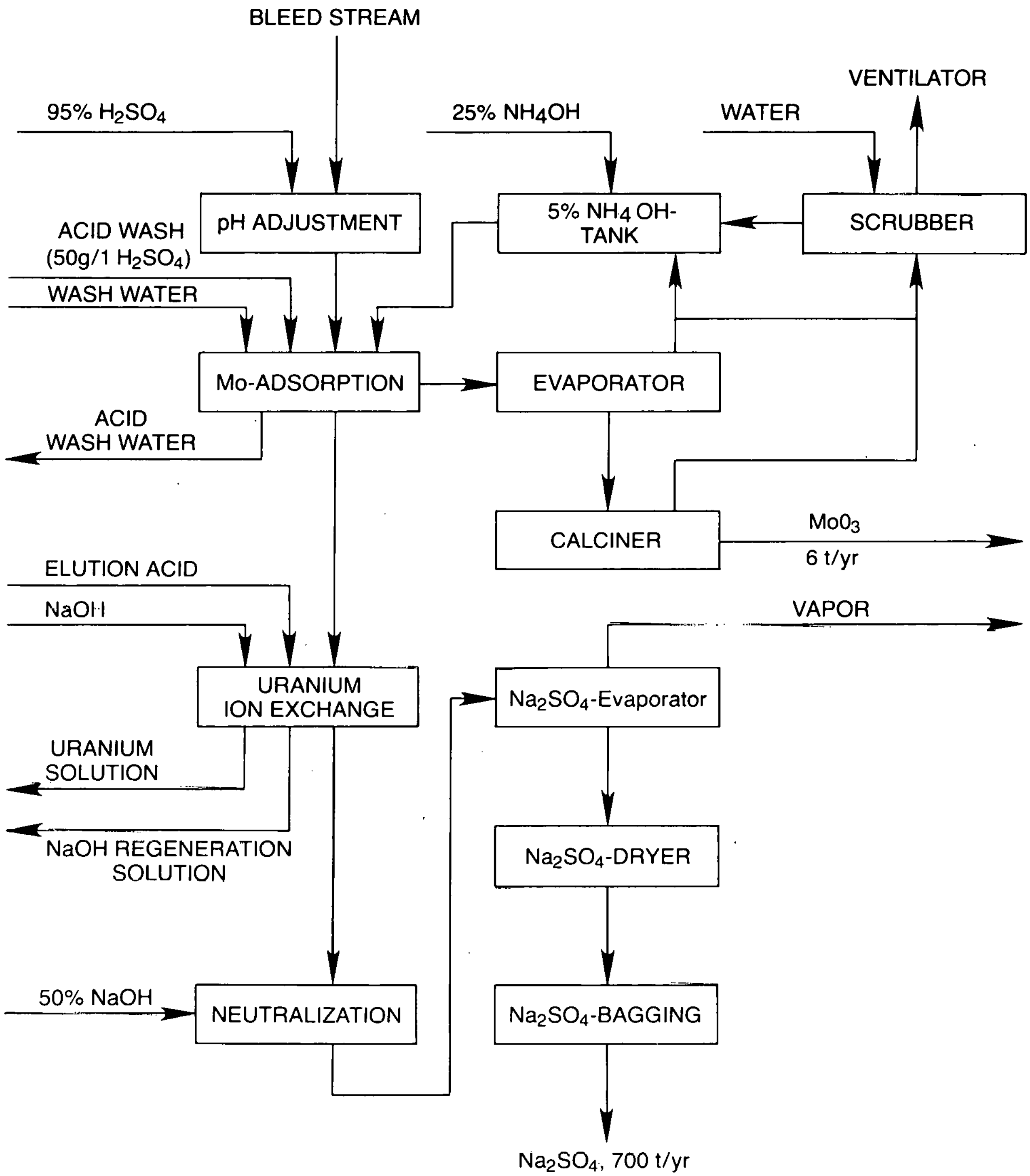


FIGURE IV-17

FLOW SHEET FOR RECOVERY OF CHEMICAL FERTILIZER-DETAIL

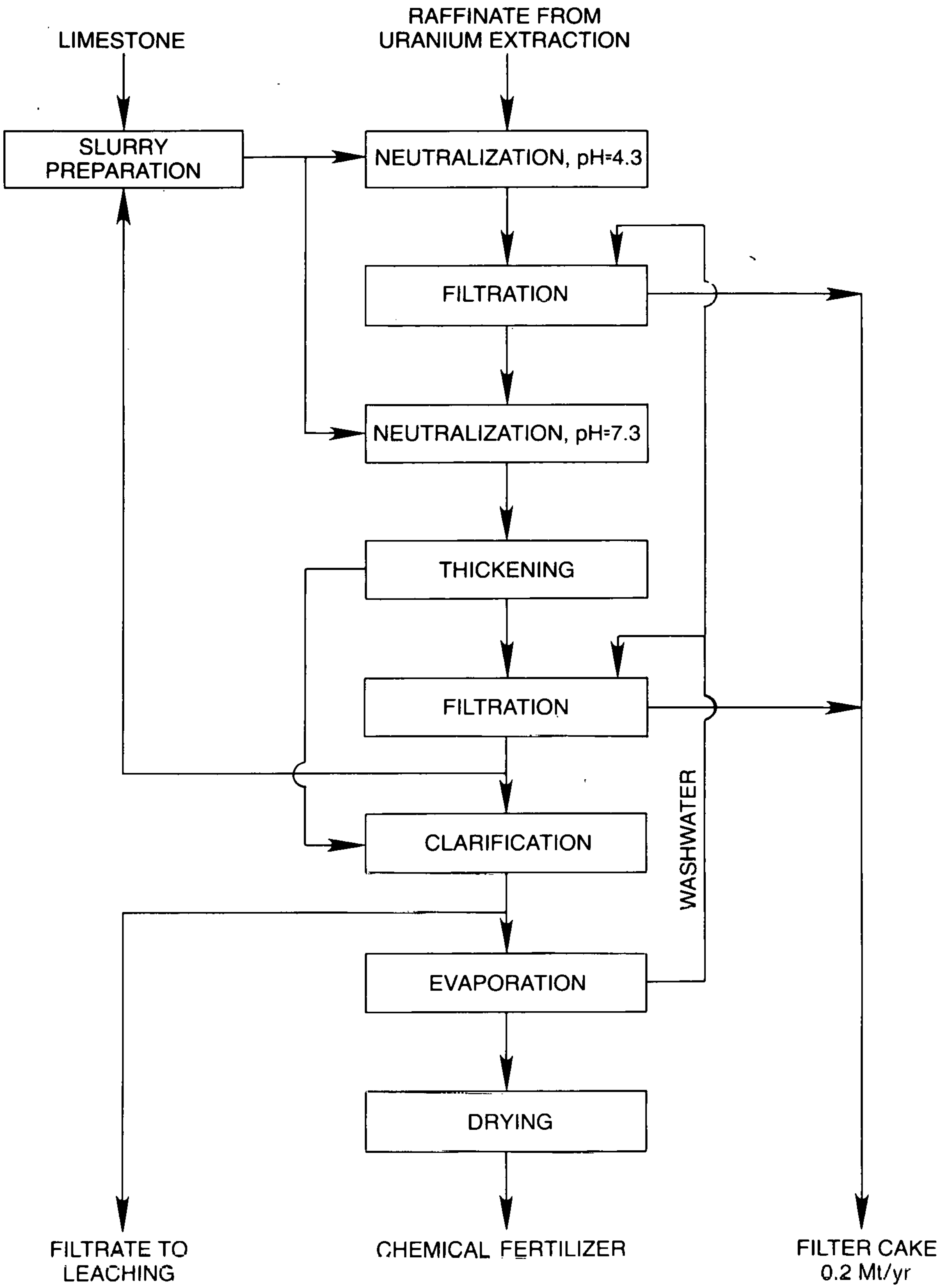


FIGURE IV-18

FLOW SHEET FOR SULFURIC ACID PRODUCTION-DETAIL

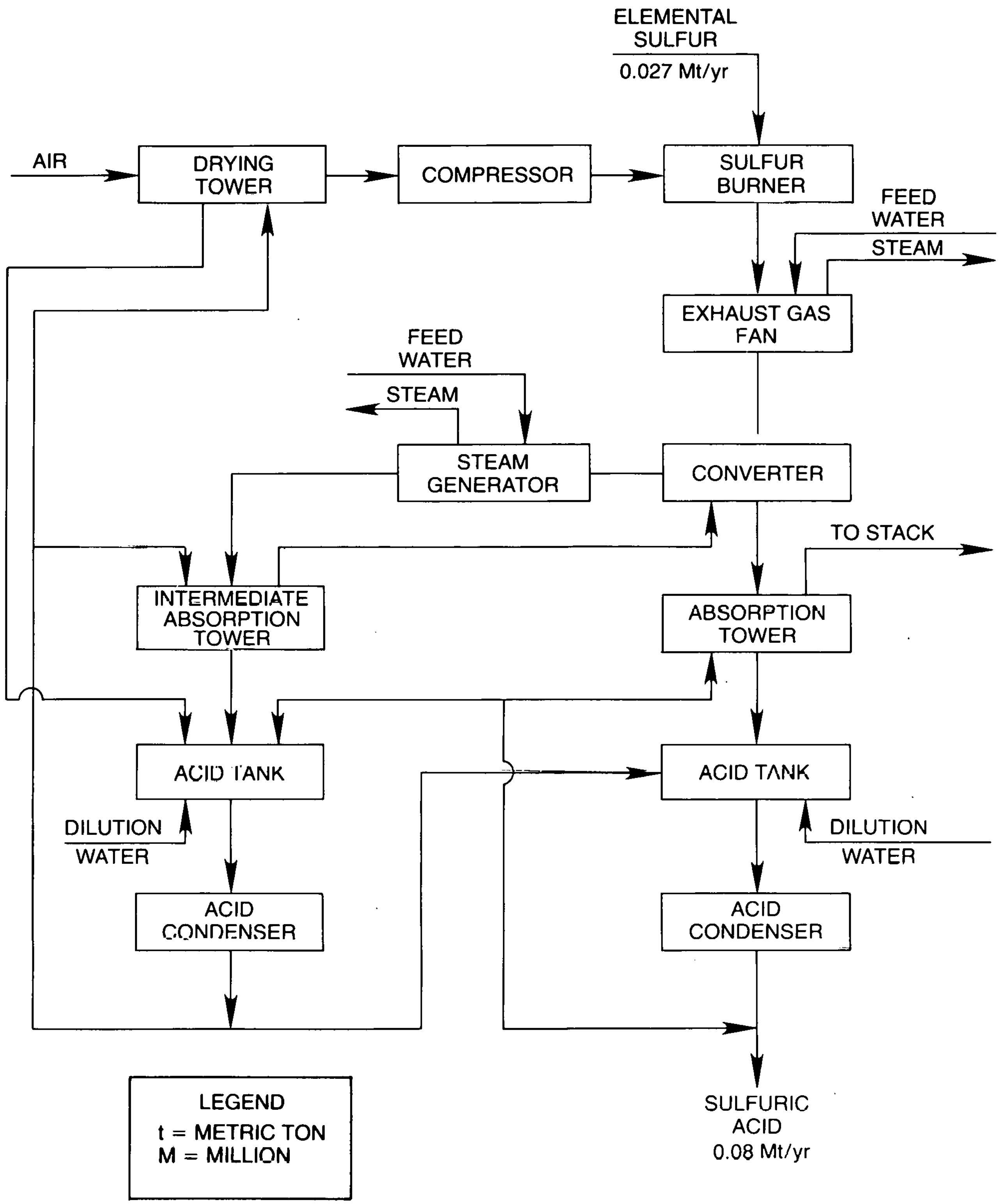


FIGURE IV-19

FLOWSHEET FOR LIMESTONE PREPARATION—DETAIL

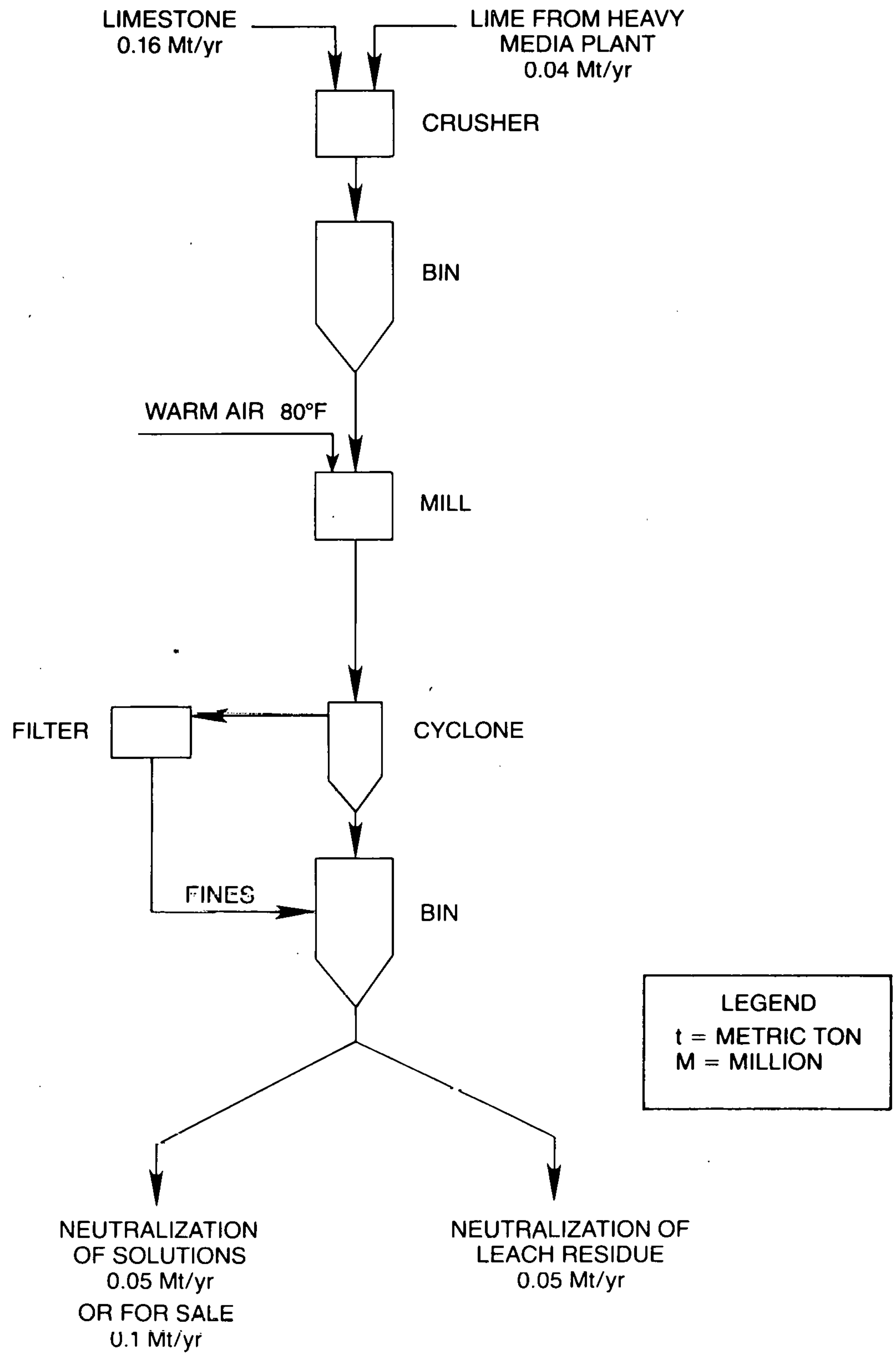
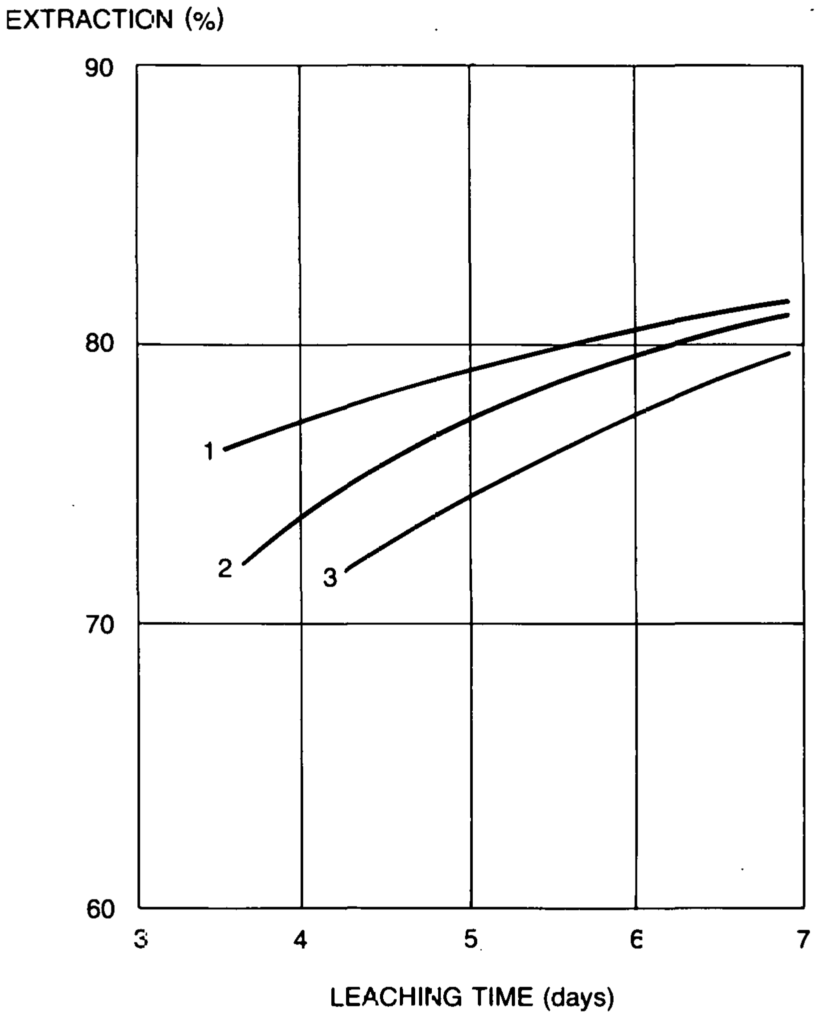


FIGURE IV-20

EXTRACTION OF URANIUM AS A FUNCTION OF LEACHING TIME AT VARIOUS TEMPERATURES (DATA FROM PILOT TESTING)



PERCOLATION LEACHING

SHALE CRUSHED TO < 2mm

MAXIMUM ACID CONCENTRATION 150 g/l

URANIUM CONTENT 300 g/t

3	35°C
2	60°C
1	90°C

FIGURE IV-21

IRON AND ALUMINUM EXTRACTIONS AS FUNCTIONS OF ACID CONCENTRATION AND LEACHING TEMPERATURE [APPROXIMATELY 30% SOLIDS, 48 HOUR LEACH]

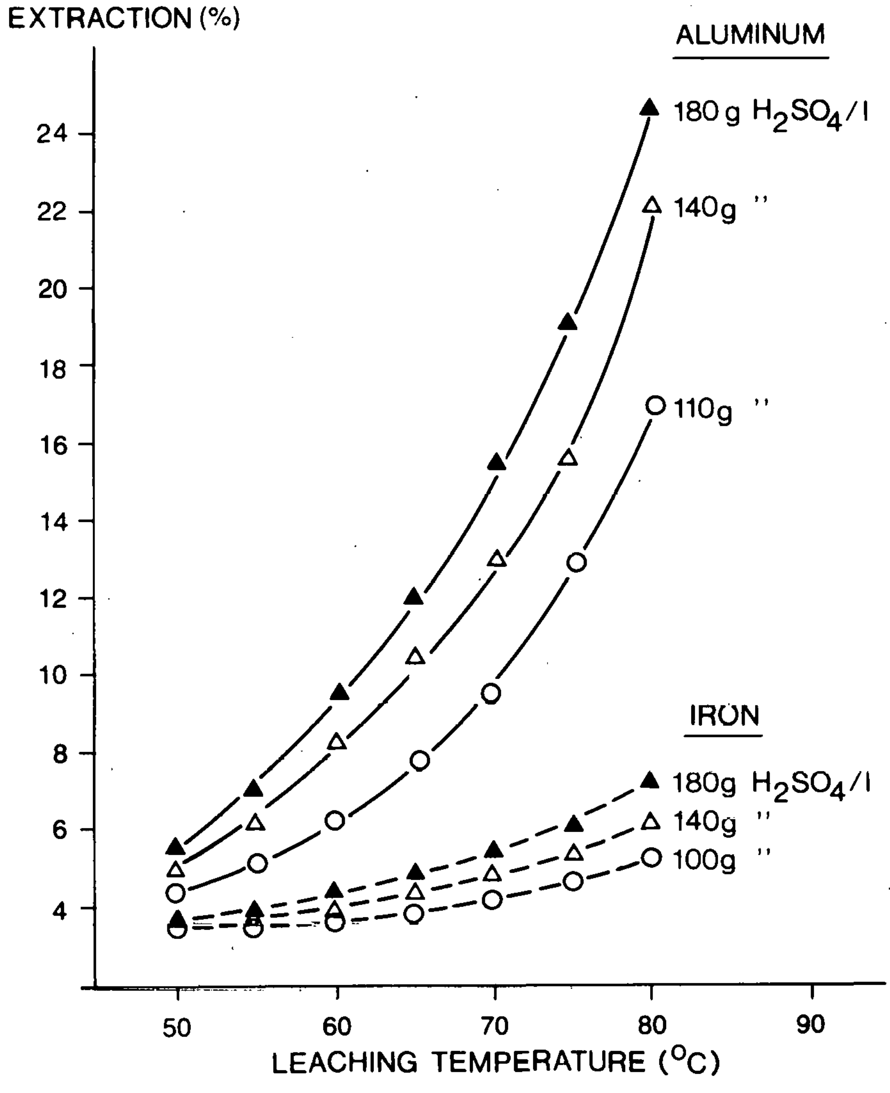
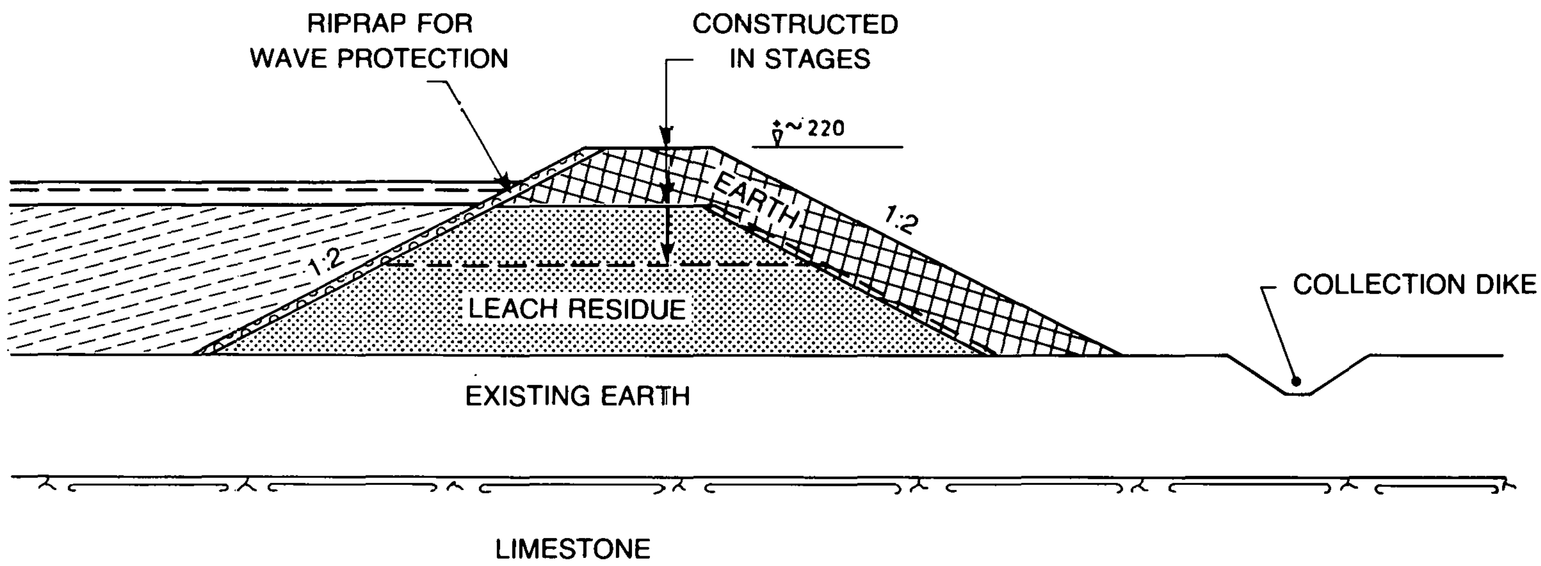


FIGURE IV-22

TAILINGS POND



WASTE POND SECTION

SCALE 1:500

FIGURE IV-23

uranium price would yield a 20 percent return on invested capital. The cost analysis showed the following variation in uranium cost as a function of tonnage treated:

Processing Rate	Cost/lb Uranium
6 million metric tons per year	$30
3 million metric tons per year	$38
1 million metric tons per year	$50

ENVIRONMENTAL CONTROLS

Elaborate precautions are taken for disposal of the solid and liquid waste streams from the plant. The solid leach residue is transported by truck to a large flat area. The finished tailing dump is graded, covered with soil and revegetated. The liquid tailings (raffinate) are neutralized with ground limestone and impounded in a large settling pond. Due to the hygroscopic nature of the precipitated metal hydroxides the ultimate percent solids is not high and the material is difficult to dispose of permanently in an environmentally acceptable manner. Water is returned from the tailings area for reuse or treatment and returned to the environment on the west side of Billingen Mountain.

Tables IV-10 through IV-13 show projected constituents of the various waste products of the production operations.

TABLE IV-10. SOLID CONSTITUENTS OF LEACH RESIDUE [a]

Constituent	Tons	Percent
U	55.6	0.0064
Mo	288.3	0.033
V	567.8	0.065
Al	52400	6.0
Fe	48900	5.6
K	33200	3.8
Na	1750	0.2
Mg	3230	0.37
Ca	7860	0.9
As	89	0.0102
Cd	0.52	0.00006
Cr	260	0.030
Cu	96	0.011
Hg	0.03	0.000031
Mn	96	0.011
Ni	114	0.013
Pb	11.4	0.0013
Sb	4.4	0.0005
Ti	3320	0.38
Zn	87	0.010
Rare Earth Metals	288	0.033
C (org)	13100	15
S (total)	64600	7.4
SiO_2	393000	45
PO_4	440	0.05
SO_4	13100	1.5

[a] The amounts correspond to 1 million tons of mined shale.

TABLE IV-11. COMPOSITION OF LEACH SOLUTIONS

Constituent	g/l	Constituent	g/l
U	0.8	Cu	0.005
Mo	0.037	Hg	< 0.0001
V	0.3	Mn	0.42
Al	17.0	Ni	0.22
Fe	10.3	Pb	3.8×10^{-6}
K	8.0 [a]	Sb	< 0.002
Na	0.4 [a]	Sn	< 0.0002
Mg	5.4 [a]	Ti	0.023
NH_4	0.8 [a]	Zn	0.090
Ca	< 0.5	Rare Earths	0.24
As	0.065	SiO_2	0.76
B	0.008	PO_4	6.2
Ba	0.05	SO_4	133
Cd	0.005		
Co	0.020		
Cr	0.050		

[a] Recirculation of process solutions

TABLE IV-12. ANALYSIS OF DRIED SALT PRODUCT FROM LEACH LIQUOR - LABORATORY TEST

Constituent	Amount	Constituent	Amount
S	23.3% (SO_4)	Ni	14
K	16.0%	SiO_2	35
Mg	10.7%	U	10
N	0.9%	Cr	2
Mn	0.4%	Sn	5
Ca	1.2%	Al	25
Na	0.8%	Cd	4
Cu	1	Pb	1
B	9	Hg	0.001
Zn	2	As	1
Co	9	V	4
Mo	25	Cl	25
Fe	25		

[a] parts per million unless otherwise indicated.

TABLE IV-13. QUANTITIES OF SUBSTANCES RELEASED IN MOISTURE CONTENT OF LEACH RESIDUE (11%) [a]

	Tons/Year	Solution mg/l
Al	0.03	0.3
Fe	0.1	1.0
K	7	60
Ca	61	560
Mg	5	40
Na	0.5	5
NH_4	0.8	8
V	0.001	<0.001
Mo	1.1	10
Cr	0.001	0.005
Ni	0.01	0.1
Cu	0.003	0.03
Mn	0.3	2.5
Zn	0.03	0.3
U	0.07	0.6
As	0.002	0.02
Pb	0.002	0.02
Sb	<0.001	<0.001
Cd	0.002	0.02
Hg	<0.001	<0.0001
Ra^{226}	$<10^{-6}$	$<0.4 \times 10^{-6}$
SO_4	200	1300
PO_4	0.03	<0.3
Co	<0.001	<0.001
Ba	0.008	0.07
Sr	0.03	0.3
Se	0.003	0.03

[a] The figures result from mining one million tons of shale per year and neutralizing with lime.

CHATTANOOGA SHALE HYDRORETORTING

Until recently oil shale development in the United States has been concentrated on the rich western shales of Colorado, Wyoming, and Utah. However, recent work at the Institute of Gas Technology (IGT), in Chicago, has shown that the Devonian shales of the eastern United States can be processed to yield more than twice as much oil as had previously been thought possible.

The kerogens contained in the Chattanooga Shale therefore, represent a highly significant energy resource when converted to a fuel such as synthetic crude oil (syncrude). Whereas previous estimates of the oil yields have been based upon Fischer assay results, work by the Institute of Gas Technology (IGT) shows that up to two and one-half times the Fischer assay yields can be obtained by retorting the Chattanooga Shale in hydrogen at controlled heating rates. Thus, the expected yield from the shale by the IGT "hydroretorting" process is expected to be approximately 0.55 barrel of syncrude per ton of shale. The new process is called hydroretorting because it is based upon controlled heating of the shale in a hydrogen atmosphere. The process has been demonstrated in experimental work and can be used to produce oil or pipeline-quality gas. Economic analyses based upon experimental hydroretorting results indicate that Devonian shales containing 10 or more weight percent organic carbon can be commercially attractive. High-grade synthetic oil can be produced from eastern shale at a cost equal to or lower than the cost of refined shale oil produced from western shale by thermal retorting.

The hydroretorting process plant planned for the Chattanooga Shale will be capable of crushing 100,000 tons per day to 1/4-inch in a single integrated crusher unit and treating the material in five parallel hydroretorting process streams. The production of syncrude comprises heating the shale to a maximum temperature of 1350°F in a hydrogen atmosphere derived from the shale effluent gases and suitably processed. Oil is separated from the retort gases. Elemental sulfur is also produced by treating effluent hydrogen sulfide by the Claus process. A further useful product recoverable for market is ammonia derived from the shale. The shale is discharged from the retorting unit and then becomes feed for the next step, uranium and other products recovery.

Potential production from the hydroretorting process includes about 55,000 barrels per day of syncrude, 2,000 long tons per day of elemental sulfur, and 500 short tons per day of ammonia.

DEVONIAN OIL SHALE RESOURCES OF THE EASTERN UNITED STATES

The U.S. Geological Survey estimates the total "known resources" of Devonian oil shale in the eastern United States (see Figure IV-24), at 400 billion barrels, and the "probable extensions of known resources" at an additional 2600 billion barrels. These estimates are based on Fisher Assay test results. Experimental work at IGT has shown that oil yields of up to 250 percent of Fischer Assay can be obtained by processing eastern shales in hydrogen at controlled heating rates. Thus, the actual magnitude of the oil present in known resources of eastern oil shales alone could be as high as 1000 billion barrels - more than eight times the total of recoverable United States oil reserves.

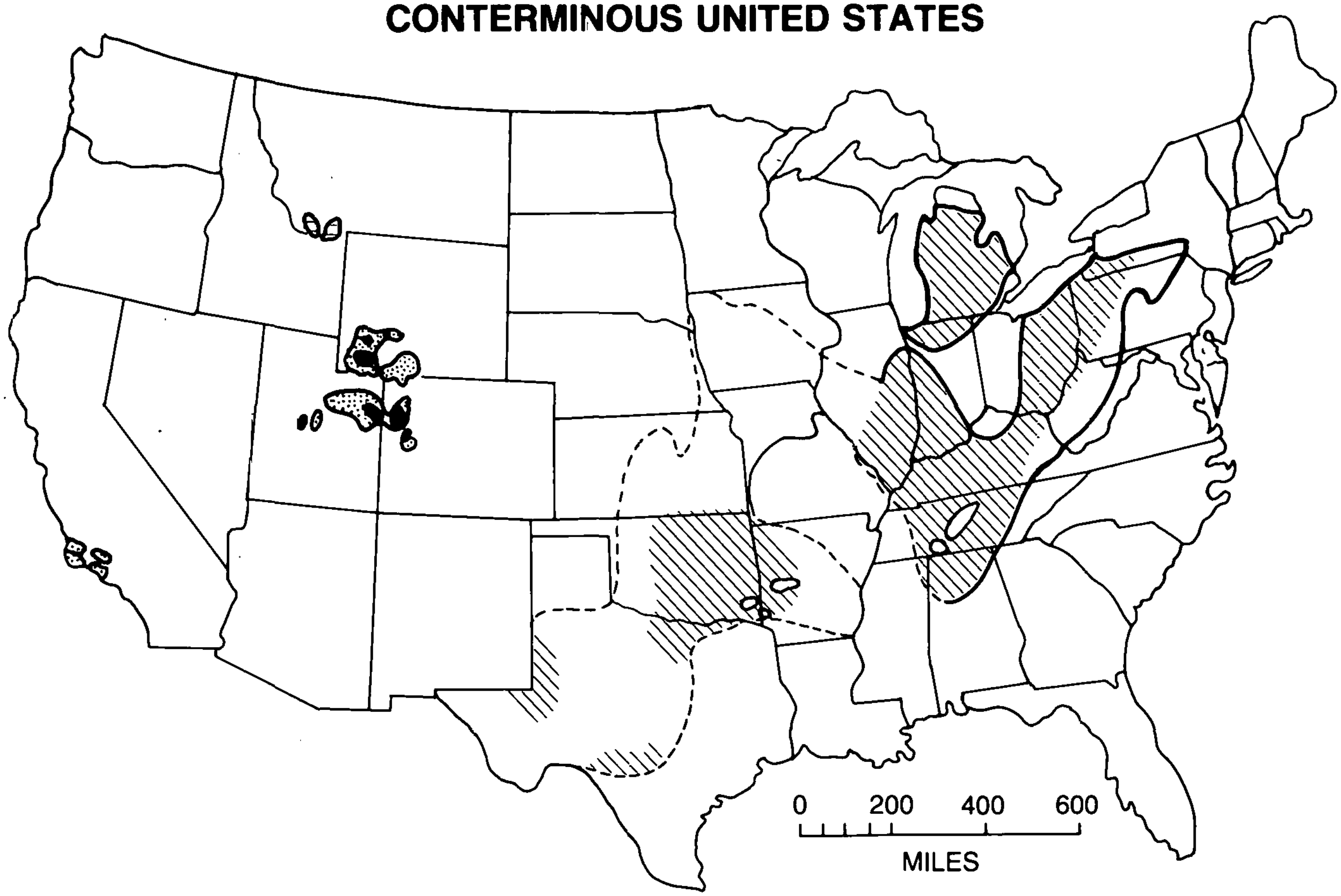
A survey program was conducted to specifically define the extent of eastern oil shale resources and to determine their suitability as hydroretorting feedstocks. This program has involved discussion with appropriate state geological survey personnel and other consultants, and the field sampling of shales. Results of the survey are shown in Table IV-14.

Estimates of the extent of the resources of Devonian oil shale in the Appalachian, Illinois, and Michigan Basin areas which could be recovered by surface mining and aboveground hydroretorting have been prepared. To be included in the "estimate of recoverable resources" a resource must meet the following criteria:

- Organic carbon content in excess of 10 weight percent

- Overburden thickness less than 200 feet

PRINCIPAL REPORTED OIL-SHALE DEPOSITS OF THE CONTERMINOUS UNITED STATES



Tertiary deposits Green River Formation in Colorado, Utah, and Wyoming; Monterey Formation, California; middle Tertiary deposits in Montana. Black areas are known high-grade deposits

Permian deposits Phosphoria Formation, Montana

Devonian and Mississippian deposits (USGS Resource estimates made for hachured areas only.) Boundary dashed where concealed or where location is uncertain.

FIGURE IV-24

TABLE IV-14. RESULTS OF SHALE SAMPLING PROGRAM

State	Number of Locations	Number of Samples	Rock Unit	Thickness (ft.)	Sampling Data wt. % Carbon		Published Data Fischer Assay gal/ton		Commercial Prospects
					Avg.	Max.	Avg.	Max.	
West Virginia	40	63	Millboro	1400	2.3	6.7	--	--	Uncertain
			Beaver Dam	50	1.0	1.5	--	--	
Ohio	17	40	Cleveland	60 to 100	10.6	12.6	10	15	
			Huron	300	7.0	11.9	4	10	Good
			Lower Huron	100	10.0	11.9	10	10	
Kentucky	11	60	Ohio	40 to 100	11.5	17.9	10	23	
			Sunbury	30	13.7	13.7	--	--	Good
Tennessee	16	32	Chattanooga	5 to 50	13.5	19.1	12	42	Good
Alabama	--	--	Chattanooga	5 to 40	--	--	2	3	Uncertain
Indiana	5	14	New Albany	100 to 300	10.1	15.6	--	--	
			Clegg Creek	40	14.4	15.6	--	--	Good
Illinois and Eastern Missouri	5	33	New Albany	100 to 300	5.0	9.4	--	--	Uncertain
Michigan	--	--	Antrim	100 to 650	--	--	0 to 10	17	Good
Total	94	242							

- Stripping ratio less than 2.5-to-1
- Shale thickness 10 feet or more

These criteria, which are based on coal industry practice modified to reflect the fact that the heating value of a black shale is only about one quarter that of bituminous coal, provide a conservative estimate of recoverable resources. Oil yield figures are net yields based on an integrated hydroretorting plant with no other fuel required.

A summary of known recoverable resources in the three-basin area is shown in Table IV-15. About 423 billion barrels of oil is estimated to be recoverable by aboveground hydroretorting. A typical commercial plant producing 50,000 barrels per day of oil for 20 years would require a shale deposit of about 5 square miles based on three-basin average yields; known recoverable resources are sufficient for more than 1000 such plants.

MINING OF EASTERN OIL SHALE

The economics and technology of mining eastern oil shale have been reviewed by a well-known international mining and engineering consulting firm. Their analysis shows that a truck-and-shovel opencut operation with overburden handled by draglines would be the most economical mining technique. Three cost estimates were prepared based on conditions in Ohio, Kentucky, and Tennessee. Conditions in Indiana should be similar to those in Kentucky.

The results of these cost estimates are shown in Table IV-16. The initial estimate of mine labor requirements for a single mine suggests that more than 400 men and an annual payroll of $8 million would be required at the scale shown in Table IV-16. The area of the mine would be between 3000 and 5000 acres, that is, 5 to 8 square miles for a 25-year mine life. The dimensions might be 1 mile x 5 miles, or 3 miles x 3 miles, depending upon local site considerations.

TABLE IV-15. ESTIMATED RESOURCES OF SHALE OIL RECOVERABLE BY ABOVEGROUND HYDRORETORTING IN THE APPALACHIAN, ILLINOIS, AND MICHIGAN BASIN AREAS

State	Total Area Suitable for Surface Mining, (sq mi)	Resources Recoverable by Aboveground Hydroretorting (billion bbl)	(bbl/acre)
Ohio	980	140	222,000
Kentucky	2650	190	112,000
Tennessee	1540	44	44,000
Indiana	600	40	104,000
Michigan	160	5	49,000
Alabama	300	4	21,000
Total or Average	6420	423	103,000

TABLE IV-16. COST IN SELECTED STATES FOR MINING EASTERN OIL SHALE

Location	Kentucky	Tennessee	Ohio
Mine Capacity, 10^6 tons/year [a]	25.25	19.41	33.96
Direct Mine Operating Cost, $/ton	1.60	1.90	1.75
Total Mine Investment [b], 10^6 $	112.8	135.0	176.9
Shale Price based on FPC Method, 12% DCF, 100% Equity, $/ton	2.73	3.65	3.06

[a] The mine capacities shown are approximately enough for 38,500 bbl/day of product oil in each state.

These estimates based on the following information:

- limited geological data
- selected mining costs
- established mining techniques

[b] Excluding working capital, interest during construction, and start-up cost.

No allowance has been made in the operating cost shown in Table IV-16 for severance taxes or contributions to the United Mine Workers' health, welfare, and benefits plan payments, as it is not clear at present how the mine would be operated or on what basis these payments would be made. Allowance has been made for 10 cents per ton tax payment as required by the new Federal strip-mine bill. At the present time, this tax covers coal and lignite. Coal is taxed at 10 percent or 35 cents per ton, and lignite at 2 percent or 10 cents per ton, hence oil shale with its lower unit value in the ground has been assumed to be likely to receive the lower rate.

ENVIRONMENT AND LAND RECLAMATION

Although the environmental impact of eastern oil shale development has not been fully assessed, there are reasons to expect it would be less severe than western shale development. The ecology of the area is not as fragile as that of the Green River area of Wyoming, and much of the eastern oil shale land has already been extensively mined for coal. Development of a shale industry in the East would not place as severe a strain on local water supplies as development in the Colorado and Wyoming areas. Also, eastern shale rock usually contains less than 1 percent mineral carbonates, compared with more than 15 percent for western shales. This indicates that water pollution from the leaching of soluble sodium, calcium, and magnesium salts - expected to be a major problem with Western shale - would be much less severe with eastern shales. Despite the higher population density near eastern shale reserves, it is believed these reserves could be developed in an environmentally acceptable manner.

The mining cost estimates presented include a generous allowance for land reclamation. By planning this operation as part of the integrated process, and by careful choice of inital mine site, it is possible that the land could be left in equal or better than predeveloped condition.

EASTERN SHALE HYDRORETORTING TECHNOLOGY STATUS

Initial studies of the process were directed to western shales. However, more recently the process has been applied successfully to eastern shales. Until now, eastern shales were considered to be unsatisfactory feedstocks for synfuels production (when compared with Western shales) because of their relatively low yield when assayed by the conventional Fischer Assay procedure. A comparison of the properties of typical eastern and western shales is given in Table IV-17. Although the organic carbon contents are essentially equal for these shales, the Fischer Assay oil yield of the eastern shale is less than one-half that of the western shale. However, the use of hydrogen at pressures up to 500 pounds per square inch at low shale-heating rates makes possible organic carbon recoveries up to 2.5 times those achievable by conventional retorting (Figure IV-25).

Another feature of the hydroretorting process is that, by proper selection of operating conditions, the product yields can be directed toward the production of either primarily liquid hydrocarbons or primarily gaseous hydrocarbons (SNG). Table IV-18 shows results of bench-scale hydroretorting tests. Results with western shale are included for comparison purposes.

Based on the encouraging results obtained thus far in laboratory and bench-scale tests, preliminary process flow diagrams have been prepared for aboveground manufacture of oil and SNG. Figure IV-26 shows a block-flow diagram of a plant producing low-sulfur, low-nitrogen synthetic oil from eastern shale. The hydrogen required for hydroretorting and hydrotreating is made by steam-reforming the product hydrocarbon gas.

A plant producing SNG is shown schematically in Figure IV-27. In this case, hydrogen is manufactured partly from the shale oil produced in the hydroretorting operation, and partly from recycle product gas.

Other process configurations are also possible. For example, in an area where coal is available, the hydrogen could be produced from coal by partial oxidation, and the total shale product, of hydrocarbon gas and

TABLE IV-17. COMPOSITION OF EASTERN AND WESTERN SHALES

	Eastern	Western
Ultimate Analysis, wt % (dry basis)		
Organic Carbon	13.7	13.6
Hydrogen	1.6	2.1
Sulfur	4.7	0.5
Carbon Dioxide	0.5	15.9
Ash	78.3	66.8
Fischer Assay Analysis		
Oil yield, wt %	4.6	11.4
Water yield, wt %	2.3	1.6
Loss + gas, wt %	2.4	2.6
Assay, gal/ton	10.3	29.8

ORGANIC CARBON RECOVERY WITH EASTERN SHALE IN HYDROGEN

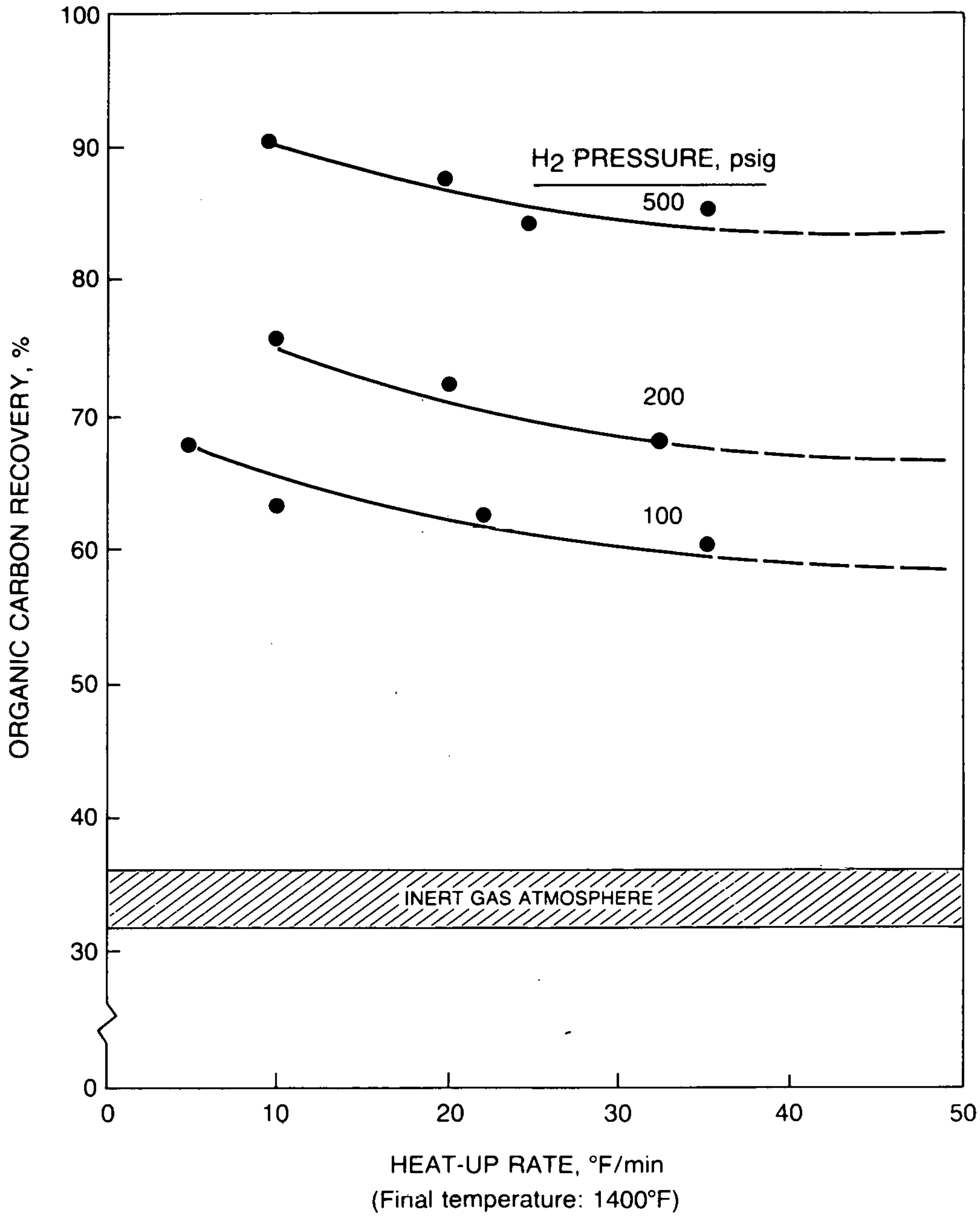


FIGURE IV-25

TABLE IV-18. BENCH-SCALE TEST RESULTS

Shale Type	Western	Eastern	
Reactor Pressure, (psig)	500	500	500
Max, Reaction Zone Temp, (°F)	1394	1483	1484
Shale Space Velocity, (lb/cu-ft/hr)	65	82	79
Hydrogen/Shale Ratio, (SCF/lb)	10.3	14.9	6.5
Organic Carbon Conversion, (%)			
To Gaseous Hydrocarbons	15	28	44
To Liquid Hydrocarbons	82	51	25
To Spent Shale	7	16	20
Percent Carbon Balance	104	95	89

SYNTHETIC OIL PRODUCTION FROM EASTERN SHALE

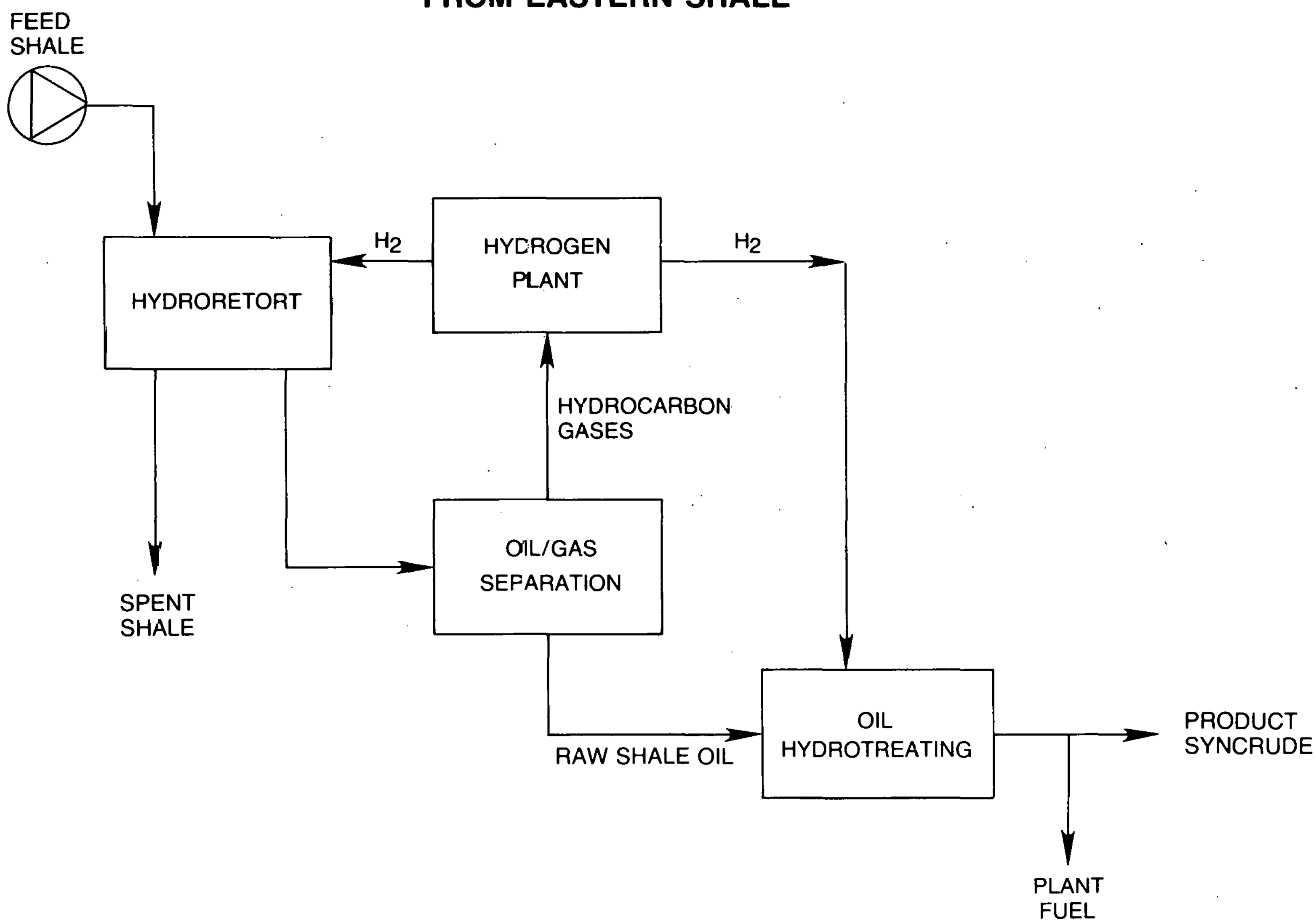


FIGURE IV-26

SNG PRODUCTION FROM EASTERN SHALE

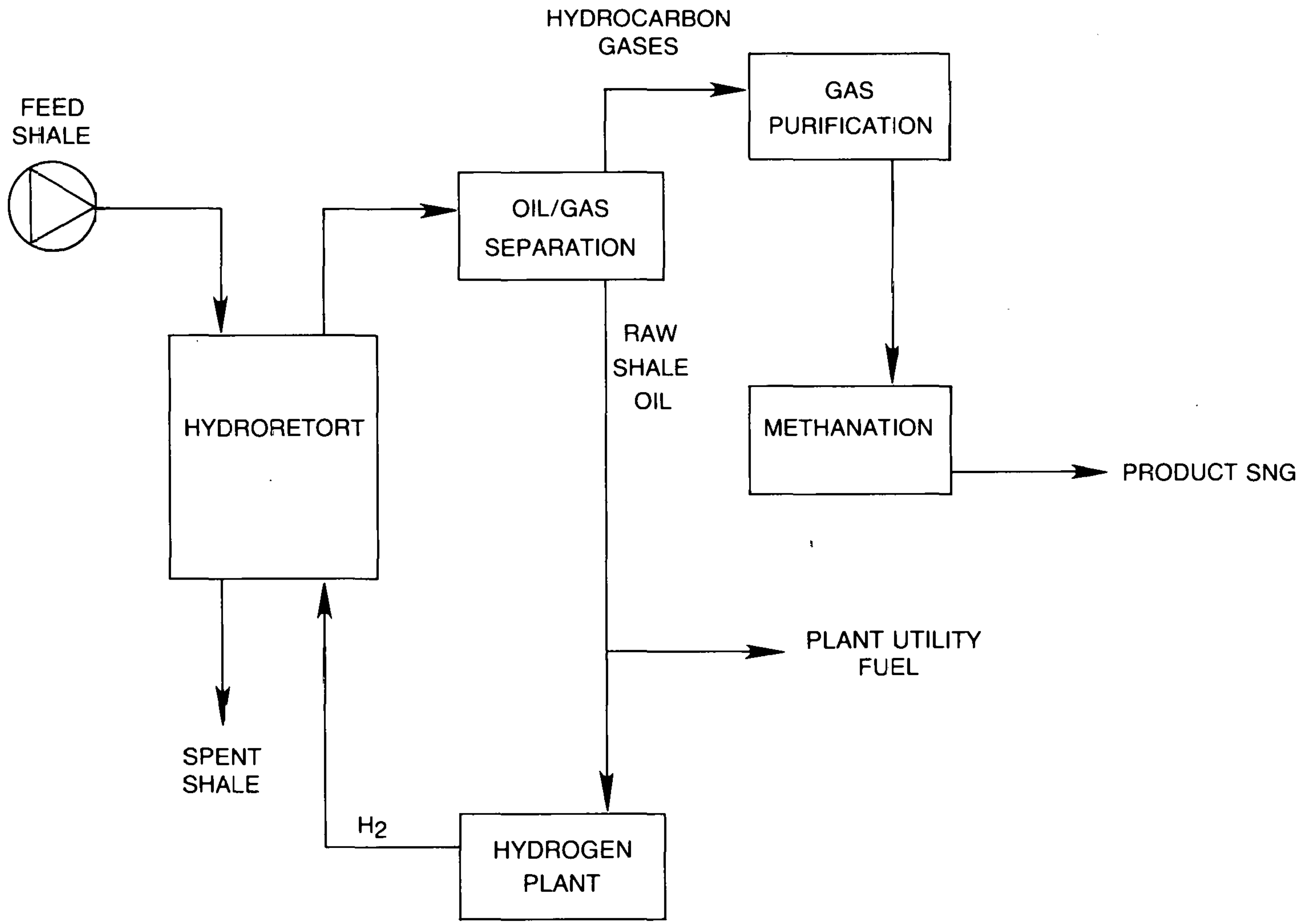


FIGURE IV-27

liquid, could be marketed. It may also be feasible to recover the heating value of unconverted kerogen in the spent shale by combustion or gasification. Choices between these process alternatives will ultimately be made on the basis of economics and efficiency.

ECONOMICS OF EASTERN SHALE HYDRORETORTING

Hydroretorting process conditions can be adjusted to produce either gas or oil. Therefore, separate preliminary estimates of the costs of producing SNG and of producing synthetic oil from eastern shales have been made. These were based on the results of the bench-scale and laboratory work on Devonian shale containing 13.6 weight percent organic carbon.

The cost of synthetic oil is estimated to be about $18.30 per barrel for a plant producing 46,200 barrels per day of a sulfur-free, low-nitrogen, 30°API product. Over 75 percent of the product oil is in the diesel-fuel or jet-fuel boiling range.

Table IV-19 gives investment and operating costs for a plant processing 92,610 tons of shale per stream day. The oil cost is based on investor-type financing at 100 percent equity with 12 percent DCF return and 15 percent depletion allowance. If 25 percent of total investment is financed by debt at 9 percent interest the product oil price is reduced to $15.60 per barrel.

The cost of synthetic pipeline gas is estimated to be about $3.11 per million Btu for a plant producing approximately 250 million cubic feet per day of SNG (heating value of 987 Btu per standard cubic foot). Table IV-20 gives investment and operating costs for a plant processing 97,860 tons of shale per stream day. Utility-type accounting procedures were used to estimate SNG costs.

TABLE IV-19. PRELIMINARY INVESTMENT AND OPERATING COSTS FOR THE PRODUCTION OF SNG BY THE IGT HYDRORETORTING PROCESS

Shale Feed, tons per stream day [a]	97,860
Plant Output, Billion BTU per stream day	250
Total Capital Investment, $ million	1,040
Net Operating Cost, $ million per year	136.2
Total Annual Revenue, $ million	262
Average Selling Price, $ per million BTU	3.19

[a] Based on a shale cost of $2.30 per ton delivered. The sensitivity of gas price is about $0.40 per million BTU for every dollar per ton change in shale cost.

TABLE IV-20. PRELIMINARY INVESTMENT AND OPERATING COSTS FOR THE PRODUCTION OF SYNTHETIC OIL BY THE IGT HYDRORETORTING PROCESS

Shale Feed, tons per stream day [a]	92,610
Plant Output	
Billion BTU per stream day	269
Barrels per stream day	46,200
Total Capital Investment, $ million	910
Net Operating Cost, $ million per year	129
Total Annual Revenue, $ million	269
Average Selling Price	
$ per barrel	18.30
$ per million BTU	3.14

[a] Based on a $2.80 per ton delivered shale cost. The sensitivity of oil price is about $2.10 per barrel for every dollar per ton change in shale cost.

CHATTANOOGA SHALE RECOVERY PLANT

Presented below is the description of a scheme of compatible integrated processes for recovering the valuable products, namely synthetic crude oil, uranium, thorium, sulfur, and ammonia, from Chattanooga Shale. A flowsheet and materials balance for the proposed processes are presented in Figure IV-28 and Table IV-21.

GENERAL PROCESS DESCRIPTION

Processing of the shale begins with an underground mine, where extraction and coarse crushing take place. Shale storage, stockpile reclamation; feeding, and fine crushing to one-fourth (1/4) inch are provided on the surface. Crushed shale is fed at the rate of 100,000 tons per day to a hydroretort similar to the one developed by the Institute of Gas Technology (IGT) and described more fully earlier in this section. In the IGT process, shale is retorted under pressure with hydrogen (530 psig) at a maximum temperature of 1350°F. The volatile components are suitably processed to evolve a "syncrude" (synthetic crude oil), hydrogen gas for recycling to the hydroretort, ammonia, and sulfur. All heat and power for the hydroretort process is developed internally from the carbon in the shale. Retorted shale, still containing about half its original sulfur and some residual carbon, is roasted. The gas from the roaster is cleaned and sent to a sulfuric acid plant which manufactures the acid that is required in the leaching operation.

The calcines from the roaster, approximately 80,000 tons per day, are ground to 48-mesh in dry ball mills, slurried to 50 percent solids, and leached by adding sulfuric acid. The leaching operation occurs in mechanical agitators with 6 hours retention time. Laboratory tests indicate that 60 percent of the uranium will dissolve, and that the sulfuric acid consumption is 200 pounds per ton of feed. The uranium-bearing solution is separated from leached solids by countercurrent decantation. Recovery of the uranium from solution is by solvent extraction with 6-benzylamino-3, 9-diethyltridecane (NBA), 0.05 molar dissolved in kerosene. Uranium is stripped from the organic solvent

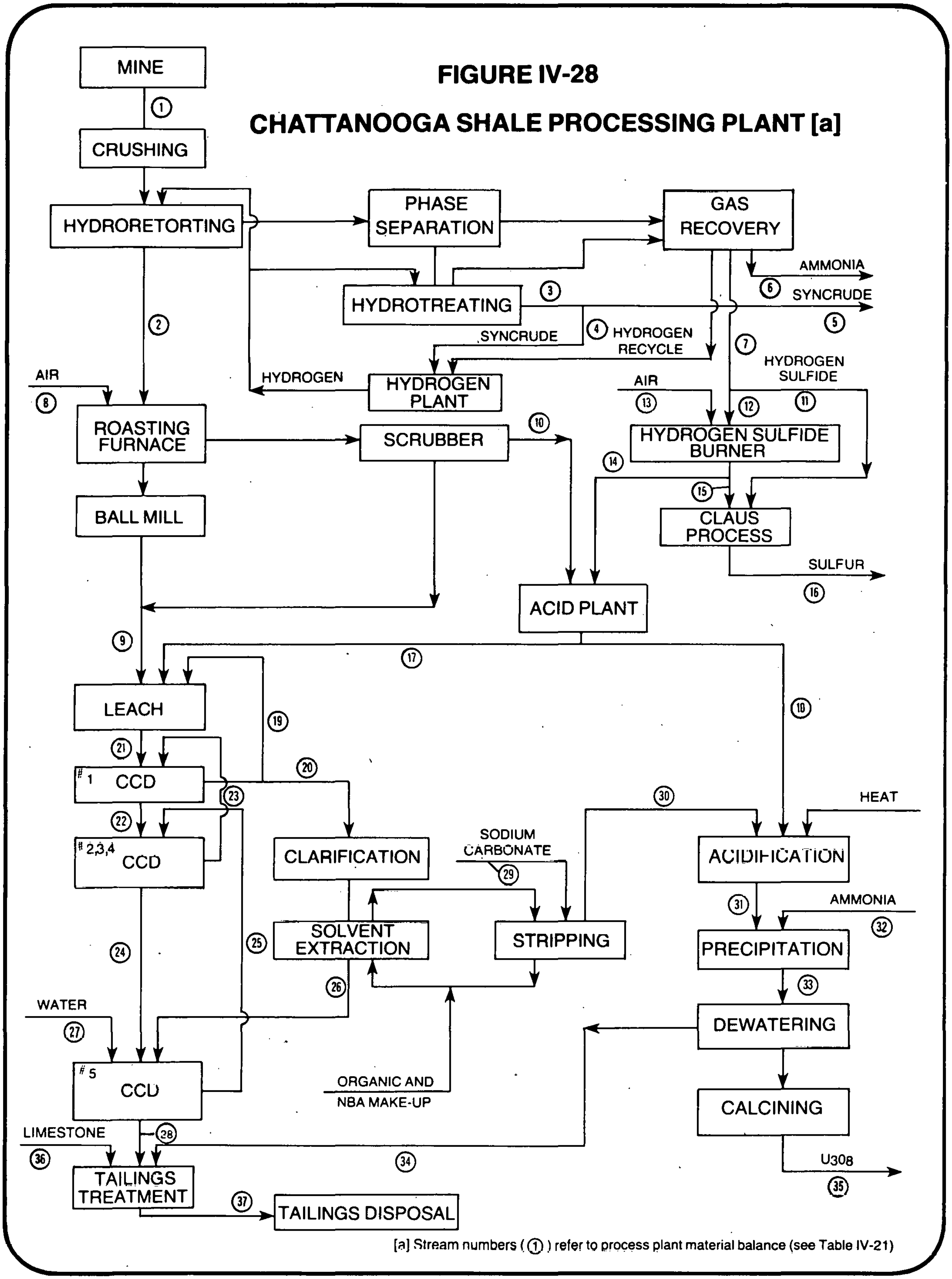


FIGURE IV-28

CHATTANOOGA SHALE PROCESSING PLANT [a]

[a] Stream numbers ((1)) refer to process plant material balance (see Table IV-21)

TABLE IV-21. PROCESS PLANT MATERIALS BALANCE

Stream Number	Stream Label	Short Tons Per Day Solids	Liquid	Gas	Total	Lb/Day Uranium
1	Plant Feed	100,000	0	0	100,000	11,000
2	Retort Ash	81,236	0	0	81,236	11,000
3	Total Syncrude	0	10,520	0	10,520	0
4	H_2 Plant Syncrude Feed	0	1,996	0	1,996	0
5	Net Syncrude Produced	0	8,524	0	8,524	0
6	Ammonia	0	0	491	491	0
7	Hydrogen Sulfide	0	0	2,588	2,588	0
8	Air to Roaster	0	0	51,776	51,766	0
9	Roaster Ash	78,669	0	0	78,669	11,000
10	Scrubber Offgas	0	0	54,343	54,343	0
11	H_2S to Claus Process	0	0	1,628	1,628	0
12	H_2S to Burner	0	0	960	960	0
13	Air to H_2S Burner	0	0	7,159	7,159	0
14	SO_2 Rich Gas to Acid	0	0	1,234	1,234	0
15	SO_2 Rich Gs to Claus	0	0	6,885	6,885	0
16	Sulfur Product	0	2,297	0	2,297	0
17	93% Acid to Leaching	0	8,459	0	8,459	0
18	93% Acid to Precip.	0	20	0	20	0
19	Leach Liquor Recycle	0	86,400	0	86,400	6,618
20	Pregnant Solution	0	86,400	0	86,400	6,618
21	Leach Slurry	80,355	93,178	0	173,532	17,618
22	#1 CCD Underflow	80,355	80,355	0	160,709	10,345
23	#2 CCD Overflow	0	159,978	0	159,978	5,962
24	#4 CCD Underflow	80,355	80,354	0	160,709	4,800
25	#5 CCD Overflow	0	159,958	0	159,958	418
26	Raffinate Recycle	0	86,397	0	86,397	18
27	Fresh Water Wash	0	73,558	0	73,558	0
28	#5 CCD Underflow	80,355	80,354	0	160,709	4,400
29	10% NA_2CO_3	0	197	0	197	0
30	Pregnant Strip Sol.	0	200	0	200	6,600
31	Precipitation Feed	0	212	0	212	6,600
32	Ammonia	0	0	1	1	0
33	Yellowcake Slurry	3	210	0	213	6,600
34	Precipitation Liquor	0	208	0	208	0
35	Uranium Product	4	0	0	4	6,600
36	Limestone Slurry	8,000	8,000	0	16,000	0
37	Tailings	88,355	88,562	0	176,917	4,400

with an aqueous sodium carbonate solution, which is then neutralized with sulfuric acid, heated, and treated with ammonia to precipitate ammonium diuranate. The diuranate is dewatered, calcined, and packaged for market.

The leaching plant tailings are neutralized with lime and are pumped at 50 percent solids to the mine site where they are classified. The coarse fraction, about 70 percent by weight, is used for mine fill, and the fine fraction (about 30 percent) is transported to a storage pond.

The integrated processing plant is designed to treat 100,000 short tons per day of Chattanooga Shale, and the estimated daily production is 49,900 barrels of synthetic crude oil, 6,700 pounds of uranium as yellow cake, 490 tons of NH_3, and 1,600 long tons of sulfur. Also vanadium, molybdenum, cobalt, nickel, and thorium may be recovered. The mine is planned to operate 350 days per work year, 20 shifts per week. The retorts and leaching plant will also operate 350 days per year.

Chemical analyses of products and plant feed materials are given in Table IV-22.

DETAILED UNIT PROCESS DESCRIPTION

Hydroretorting

A detailed description of the hydroretorting process for converting eastern oil shale to syncrude has been condensed from a report by the Institute of Gas Technology and appears earlier in this section.

Roasting

In order to eliminate the sulfur from the hydroretorting residue, a roasting operation is included. This roasting is necessary for economy and safety in leaching. The gas from the roaster is scrubbed to remove dust, which is routed to the leaching circuit. The gas is routed to the sulfuric acid plants where it joins, if necessary, SO_2 derived from

TABLE IV-22. MINERALOGICAL AND CHEMICAL ANALYSIS OF PLANT FEED AND PRODUCTS

	Analysis (percent wt)	
	Retort Feed	Roasted Residue [a]
Organic Carbon	12.99	
Aromatic Hydrocarbons	0.46	
Aliphatic Hydrocarbons	16.19	
Uranium	0.0055	0.0069
Molybdenum	0.02	0.025
Vanadium	0.076	0.095
Sulfur	4.86	
Total Iron	4.91	6.14
Kaolinite	2.92	
Illite	22.22	
Hydrogen	1.68	
Carbonate Carbon	0.69	
Nickel	0.053	0.066
Cobalt	0.023	0.029
Thorium	0.0010	0.0013

[a] Upgrading through weight loss of 20%.

incinerating H_2S from the hydroretort plant. Thus, the entire 8,000 tons per day of sulfuric acid needed for leaching are provided internally, still leaving a surplus of marketable elemental sulfur from the hydroretort section. Ten parallel roasting furnaces, each handling 8000 tons per day of hydroretort residue, are estimated for the operation.

Uranium Leaching and Recovery

Roasted shale is prepared for sulfuric acid leaching by grinding the minus 1/4-inch material to 48-mesh in dry, open circuit ball mills. As an optimum choice of equipment size, 15.5-foot diameter by 26-foot long open-circuit mills have been selected, each equipped with a 3,500 horsepower electric motor drive. Thus, ten parallel grinding and leaching ciruits for convenience and efficiency are indicated to handle the 80,000 tons of roasted feed per 24 hours, or 8,000 tons per circuit.

The ground feed is then slurried to 50 percent solids with recycled leaching solution. Sulfuric acid, 200 pounds of acid per ton of material treated, is added to the slurry, and agitation in stirred vessels is commenced. Six hours total leaching contact for each of the 10 lines is provided in four 32-foot by 32-foot agitators in series (125 horsepower each). Leached slurry proceeds to a 5-stage countercurrent decantation system for separation of the uranium-bearing solution from tailings. High-capacity thickeners, 50 feet in diameter, are selected. A suitable flocculating agent is added to each stage in amounts totalling 0.20 pound per ton.

Part of the solution decanted from the first countercurrent thickener proceeds to a clarifying filter enroute to the solvent extraction step (the remainder of the decanted solution is recycled to the grinding unit). To provide mixing of the NBA kerosene organic extractant and subsequent separation of the barren aqueous acid solution (raffinate) from the uranium-loaded organic phase, the application of a relatively newly developed electrostatically-accelerated mixer-settler device is planned.

The organic is stripped of its uranium with a sodium carbonate solution and returned to the solvent extraction circuit. Uranium-bearing sodium carbonate solution is neutralized with sulfuric acid, heated to expel carbon dioxide, and treated with ammonia to precipitate ammonium di-uranate. The precipitate is dewatered, calcined, and packaged for market. It is planned that the uranium solution from each pair of leaching circuits will be combined for solvent extraction, so that five mixer-settler and stripping units are required. In turn, the uranium-bearing sodium carbonate solution from all five S-X units will be combined for precipitation in a single product process.

Tailings Disposal

The washed mill tailings leave the leaching plant in the form of a 50 percent solids slurry. The stream will be treated with a slurried mixture of ground limestone to neutralize excess acidity and to precipitate soluble elements such as iron and aluminum. As much of the coarser fraction of the tailings as possible will be returned underground for disposal and to support mined areas. Of the 80,000 tons of dry solids tailings per day, about 70 percent or 56,000 dry tons will be returned underground in the form of a 50 percent solids slurry. The sand-slime separation will be accomplished in wet cyclones, fed with a 30 percent slurry (after dilution with recycled water). Cyclone overflow of the fine portion at 13 percent solids will be thickened in high-efficiency thickeners and then piped to a tailings storage area. All return water will be pumped back to process plant storage for reuse.

NET ENERGY YIELD FROM CHATTANOOGA SHALE

The net energy yield from various constituents of the Chatanooga Shale has been calculated and is presented in simplified form in Tables IV-23 through IV-26. Various necessary assumptions in regard to reactor cycles, types, and fuels are indicated in the Tables.

TABLE IV-23. GROSS ENERGY IN ONE TON OF BITUMINOUS COAL COMPARED TO ONE TON OF CHATTANOOGA SHALE (WITH URANIUM BURNED IN THE LWR WITH THROWAWAY CYCLE)

	BTU	kWh
Bituminous Coal [a]		
Gross energy at 10,000 BTU per pound	20,000,000	5,860
Chattanooga Shale		
Gross energy from recoverable and fissionable portion of 55 PPM U	34,000,000	9,962
Energy from kerogen	3,987,000	1,168
TOTAL	37,987,000	11,130

[a] Source: Battelle Pacific Northwest Laboratories [1974]

TABLE IV-24. NET ELECTRICAL ENERGY IN ONE TON OF BITUMINOUS COAL COMPARED TO NET ENERGY FROM FISSIONING RECOVERABLE URANIUM IN ONE TON OF CHATTANOOGA SHALE (WITH URANIUM BURNED IN THE LWR WITH THROWAWAY CYCLE)

	kWh per Ton
Bituminous Coal	
10,000 BTU per pound coal [a] 36% power plant efficiency	2,110
Chattanooga Shale	
LWR, throwaway cycle, energy from recoverable and fissionable portion of 55 ppm U	1,178

[a] Source: Battelle Pacific Northwest Laboratories [1974]

TABLE IV-25. NET ELECTRICAL ENERGY IN ONE TON OF BITUMINOUS COAL COMPARED TO NET URANIUM ENERGY PLUS OTHER SOURCES OF REALIZABLE ENERGY IN ONE TON OF CHATTANOOGA SHALE (IN THE LWR WITH RECYCLE OF PLUTONIUM)

			kWh per Ton
Bituminous Coal			
10,000 BTU per pound coal, 36% power plant efficiency			2,110
Chattanooga Shale			
Energy from recoverable and fissionable portion of 55 PPM U in LWR, with nuclear fuel recycle, plus other realizable power	Uranium	1,850	
	Thorium	-	
	Syncrude [a]	315	
	Ammonia [a]	19	
	Sulfur [a]	18	
	Elec. Power	31	
			2,241

[a] Electrical energy equivalent for production of these products

TABLE IV-26. NET ELECTRICAL ENERGY IN ONE TON OF BITUMINOUS COAL COMPARED TO NET TOTAL ENERGY REALIZABLE THROUGH BREEDER REACTOR CYCLE PLUS THERMAL SOURCES IN ONE TON OF CHATTANOOGA SHALE

			kWh per Ton
Bituminous Coal			
10,000 BTU per pound coal, 36% power plant efficiency			2,110
Chattanooga Shale			
All sources; breeder cycle for uranium and thorium	Uranium	185,000	
	Thorium	12,700	
	Syncrude	315	
	Ammonia	19	
	Sulfur	18	
	Power	39	
			198,091

As shown, Chattanooga Shale contains greater gross energy than does a ton of good grade bituminous coal. The net energy from the recoverable and fissionable uranium in the shale, when burned in the current-technology light water reactors (LWR) with throwaway cycle, is half that of the coal. In the LWR with plutonium recycle and using other thermal energy in the shale, the yield is comparable to the coal. Using the breeder reactor cycle and the thermal energy, the total net energy in a ton of Chattanooga Shale is 94 times as great as that in a ton of bituminous coal.

USE OF THORIUM IN ATOMIC ENERGY

Thorium, a fertile isotope in itself, can result in a fissile isotope, U_{233}, upon suitable neutron bombardment in a breeder reactor. Thus, thorium is of potential usefulness in atomic energy to a degree only slightly inferior to U_{235} by the ratio of their respective atomic weights. Of course, neutronically it is slightly better than U_{235} in thermal neutron reactors. In general, the fissile isotopes are U_{233}, U_{235}, Pu_{239}, and Pu_{241}, plus the transuranium isotopes which have only short half lives.

Current studies suggest that present economics do not favor use of thorium as fuel, nor is it favored by the current attitude toward breeder reactors. However, the potential energy of both natural uranium and thorium in the breeder reactor cycle compels attention, particularly in the context of restricted uranium supplies and availability.

Of interest is the crossed progeny fuel cycle system which uses both U_{238} and Th_{232} synergistically in pairs of reactors fueled by the fissile product of the opposite number of the pair, i.e., plutonium is used to enrich thorium, converting it to U_{233}, and the U_{233} is used in the other reactor to enrich U_{238} to produce more plutonium. The reactor pairing system involves considerable chemical separations and fuel processing. The crossed progeny system which offers the possibility of providing an excellent fuel for light water reactors, is at the same time more proliferation-resistant, and has the energy efficiency in regard to uranium utilization of a plutonium breeder reactor.

References of interest on potential reactor cycles and use of thorium are listed briefly here and more fully in Section VI:

Battelle Pacific Northwest Laboratories. Some Alternatives to the Mixed Oxide Cycle.

Chang, et al. Alternative Fuel Cycle Options; Performance Characteristics and Impacts in Nuclear Power Growth Potential.

Energy Research and Development Administration. Resources, Fuel and Cycles, and Proliferation Aspects.

Eschbach. Plutonium Value Analysis. 1964.

Eschbach. Crossed Progeny and Some Other Nonstandard Fuel Cycles.

Matzie and Rec. Assessment of Thorium Fuel Cycles in Pressurized Water Reactors.

Mitre Corporation. Nuclear Power Issues and Choices.

Oak Ridge National Laboratory. Assessment of the Thorium Fuel Cycle in Power Reactors.

SECTION V
ECONOMIC EVALUATION

Based upon the various aspects of recovery operations discussed in the preceding sections, and the characteristics of the ore itself, the following analysis of the economic feasibility of large-scale production of uranium from Chattanooga Shale is presented.

DEFINITIONS AND QUALIFICATIONS

The economic evaluation of processing Chattanooga Shale has been made for several different cases, with different assumptions regarding the product or group of products being recovered, and regarding whether the price is fixed at $42.50 per pound of U_3O_8 ($50.12 per pound U) or other specified price, or allowed to seek the price level needed to provide 20 percent or 15 percent return on investment (R.O.I.). The assumptions for each case are outlined as follows:

Case 1. Products recovered are syncrude, uranium, sulfur, ammonia, vanadium, cobalt, nickel, molybdenum, thorium, and electricity

- Subcase 1 - Raw shale containing 55 ppm U at $50.12 per pound U, $14 per barrel syncrude price, percent R.O.I. sought
- Subcase 2 - Raw shale containing 85 ppm U at $50.12 per pound U, $14 per barrel syncrude price, percent R.O.I. sought
- Subcase 3 - Raw shale containing 55 ppm U, $14 per barrel syncrude price, 20 percent R.O.I., uranium price sought
- Subcase 4 - Raw shale containing 55 ppm U, $14 per barrel syncrude price, 15 percent R.O.I., uranium price sought
- Subcase 5 - Raw shale containing 55 ppm U, $20 per barrel syncrude price, 15 percent R.O.I., uranium price sought
- Subcase 6 - Raw shale containing 55 ppm U, $20 per barrel syncrude price, 20 percent R.O.I., uranium price sought
- Subcase 7 - Raw shale containing 85 ppm U, $20 per barrel syncrude price, 15 percent R.O.I., uranium price sought
- Subcase 8 - Raw shale containing 85 ppm U, $20 per barrel syncrude price, 20 percent R.O.I., uranium price sought

Case 2. The products recovered are syncrude, uranium, sulfur, ammonia, and electricity

Subcase 1 - Raw shale containing 55 ppm U at $50.12 per pound U, $14 per barrel syncrude price, percent R.O.I. sought

Subcase 2 - Raw shale containing 85 ppm U at $50.12 per pound U, $14 per barrel syncrude price, percent R.O.I. sought

Subcase 3 - Raw shale containing 55 ppm U, $14 per barrel syncrude price, 20 percent R.O.I., uranium price sought

Subcase 4 - Raw shale containing 55 ppm U, $14 per barrel syncrude price, 15 percent R.O.I., uranium price sought

Subcase 5 - Raw shale containing 55 ppm U, $20 per barrel syncrude price, 20 percent R.O.I., uranium price sought

Subcase 6 - Raw shale containing 85 ppm U, $20 per barrel syncrude price, 15 percent R.O.I., uranium price sought

Subcase 7 - Raw shale containing 55 ppm U, $271.18 per pound U, 20 percent R.O.I., price of syncrude sought

Subcase 8 - Raw shale containing 55 ppm U, $50.12 per pound U, $20 per barrel syncrude price, percent R.O.I. sought

Subcase 9 - Raw shale containing 55 ppm U, $20 per barrel syncrude price, 20 percent R.O.I., uranium price sought

Case 3. Only uranium is recovered

Subcase 1 - Raw shale containing 55 ppm U, 20 percent R.O.I., uranium price sought

Subcase 2 - Raw shale containing 85 ppm U, 20 percent R.O.I., uranium price sought

Subcase 3 - Raw shale containing 55 ppm U, 15 percent R.O.I., uranium price sought

Subcase 4 - Raw shale containing 85 ppm U, 15 percent R.O.I., uranium price sought

Subcase 5 - Raw shale containing 130 ppm U, 20 percent R.O.I., uranium price sought

Subcase 6 - Raw shale containing 45 ppm U, 20 percent R.O.I., uranium price sought

Subcase 7 - Raw shale containing 55 ppm U, 70 percent U recovery instead of the 60 percent assumed in other subcases, 20 percent R.O.I., uranium price sought

Subcase 8 - Raw shale containing 55 ppm U, 80 percent U recovery instead of the 60 percent assumed in other subcases, 20 percent R.O.I., uranium price sought

Case 4. Only uranium and by-product metals are recovered.

Subcase 1 - Raw shale containing 55 ppm U, 15 percent R.O.I., uranium price sought

Subcase 2 - Raw shale containing 55 ppm U, 20 percent R.O.I., uranium price sought

A list of each case and subcase with the various assumptions made is presented in Table V-1.

TABLE V-1. ECONOMIC EVALUATION CASES

	U-ppm	U-rec.	U Price ($/lb)	Syncrude Price ($/bbl)	R.O.I. (%)	Payout Years (sought)
<u>Case 1</u>						
1	55	60	50.12	14.00	8.87 (seek)	8.1
2	85	60	50.12	14.00	11.11 (seek)	6.7
3	55	60	221.23 (sought)	14.00	20.00	3.7
4	55	60	132.16 (sought)	14.00	15.00	5.1
5	55	60	82.03 (sought)	20.00	15.00	5.1
6	55	60	172.44 (sought)	20.00	20.00	3.7
7	85	60	53.08 (sought)	20.00	15.00	5.1
8	85	60	111.58	20.00	20.00	3.7
9	55	60	50.12	20.00	12.80 (seek)	5.9
<u>Case 2</u>						
1	55	60	50.12	14.00	-0.87 (seek)	23.0
2	85	60	50.12	14.00	2.85 (seek)	14.7
3	55	60	283.02 (sought)	14.00	20.00	3.7
4	55	60	203.88 (sought)	14.00	15.00	5.1
5	55	60	234.23 (sought)	20.00	20.00	3.7
6	85	60	99.48 (sought)	20.00	15.00	5.1
7	55	60	271.18	15.45 (seek)	20.00	3.7
8	55	60	50.12	20.00	5.63 (seek)	10.9
9	55	60	153.74 (sought)	20.00	15.00	5.1

TABLE V-1. ECONOMIC EVALUATION CASES (Continued)

	U-ppm	U-rec.	U Price ($/lb)	Syncrude Price ($/bbl)	R.O.I. (%)	Payout Years (sought)
<u>Case 3</u>						
1	55	60	271.18 (sought)	--	20.00	3.9
2	85	60	175.47 (sought)	--	20.00	3.9
3	55	60	242.46 (sought)	--	15.00	5.3
4	85	60	156.89 (sought)	--	15.00	5.3
5	130	60	114.73 (sought)	--	20.00	3.9
6	45	60	331.45 (sought)	--	20.00	3.9
7	55	70	232.44 (sought)	--	20.00	3.9
8	55	80	203.39 (sought)	--	20.00	3.9
<u>Case 4</u>						
1	55	60	170.59 (sought)	--	15.00	5.2
2	55	60	208.44 (sought)	--	20.00	3.8

Various other factors bearing upon the economic analysis for each case are listed below:

- The percent metal recoveries for this economic evaluation are: uranium - 60%, 70%, 80%; vanadium - 40%; cobalt - 60%; nickel - 60%; molybdenum - 60%; and thorium - 60%.

- In cases where waste heat is recovered in boilers and converted to electricity and process steam, additional capital has been provided for an expanded power plant, larger than that required for the syncrude unit. Suitable increased operating costs for the expanded power plant have also been included where appropriate.

- In the cases wherein co-products besides syncrude, uranium, ammonia, sulfur, and electricity are assumed to be recovered, the solvent extraction and product recovery capital and operating cost estimates have been increased as deemed necessary.

  The results of the computer analysis of the various cases defined above are presented in pages V-11 through V-64 appearing at the end of this section.

- When only uranium is assumed to be recovered, the hydroretorting, roasting, acid plant, and expanded power plant capital and operating costs are eliminated.

- It is estimated that raw shale will respond to acid leaching with an acid consumption of 200 pounds of H_2SO_4 per ton. Sulfuric acid, power, and fuels are purchased when uranium is the only product.

The following additional financial guidelines were used for computer programming:

- All computer printout cashflow in dollars x 10^6
- Federal income tax at 48 percent (plus 2 percent state tax)
- Depletion at 22 percent of sales, or 50 percent of net

- Investment tax credit at 10 percent applied to 80 percent of capital
- Net before depletion = sales - operating costs - depreciation
- Depletion = smaller of 1) depletion allowance* x gross sales
  2) 50% net before depletion

*Syncrude 15%; U, S, V, G, Ni, Mo, Th 22%; NH_3, KWH 0%

- Taxable income = net before depletion - depletion
- Normal tax = 48% taxable income
- Total tax credit = 10% of 80% of capital
- Annual tax credit limit = 25,000 + 50% (normal tax - 25,000)
- Minimum tax = 15% x (depletion - (normal tax - tax credit))
- Income taxes = normal tax + minimum tax + 2% taxable income (state tax)
- Net income = taxable income + tax credit - taxes
- Gross cash flow = net income + depreciation + depletion
- Net cash flow = gross cash flow - capital - working capital
- Minimum tax on preference income per 1976 tax laws [Dept. of Treasury, 1977 Tax Guide, Ch. 31, p. 152, 153]
- Straight-line depreciation over 12 years
- Equity financing
- 20-year mine life
- Working capital equal to 3 months operating expenses
- No salvage value

BASIS AND METHODS FOR OPERATING COST ESTIMATE

The operating cost estimates for the processing of Chattanooga Shale are based upon cost estimates provided by The Cleveland-Cliffs Iron Company, for mining of the shale; the Institute of Gas Technology, for hydroretorting the crushed shale; and Mountain States Research and Development, for uranium and by-product recovery.

Cost estimates include process and mining flowsheets, design criteria, major equipment prices, utilities requirements, personnel needs, employee benefits, and costs of reagents and supplies. Personnel costs are based upon a canvas of various operating plants in the general area of the proposed shale processing facility. Payroll burden is calculated as a percentage of the total cost of labor. Maintenance costs are also expressed as a percentage of total capital investment. Operating supply costs are calculated from estimated actual consumption and 1978 market prices. In cases where the supplies are manufactured at the processing facility itself, the cost of manufacture is used.

Kilowatt-hours are estimated from the total installed horsepower, with average load factors for the different types of equipment. The average cost of power purchased and generated internally is estimated at 2 cents per kilowatt-hour.

BASIS FOR CAPITAL COST ESTIMATES

The capital cost estimates included in this feasibility study are for processing Chattanooga Shale in the four cases defined earlier, and are based upon the data, conditions, and assumptions discussed below. Accuracy of this capital cost study is estimated to be within 30 percent.

The estimates are based upon May, 1978 prices, and no escalation allowances are included. A contingency allowance of 20 percent has been used and is considered reasonable for feasibility estimates of the magnitude of this project. Source of funds has not been identified in this study. The estimate is based upon flow diagrams, specifications of major equipment, and cost appraisals made by MSRD.

The preparation of logic networks and schedules has not been attempted. For estimating purposes, it has been assumed that engineering, procurement, and construction of the uranium facilities will be completed by one contractor over a period of 52 months, the last 45 months including construction with an average manpower of approximately 1,550 craftsmen. Availability of skilled craftsmen for construction of the uranium facilities is assumed consistent with schedule requirements.

Because of the Chattanooga Project requirements, much of the process equipment is of a size requiring custom manufacturing. Process equipment costs are based upon recent similar purchases and information provided by knowledgeable industry sources.

Total capital cost has been determined by applying a factor of 3.25 to process equipment costs and adding allowance for tailings disposal. The factor appears consistent with historical data for projects similar in type and magnitude. Allowance for tailings is based upon returning 70 percent of solids to the mine, and emplacing the remaining 30 percent of solids in a 1-year capacity tailings pond with annual expansion taken as an operating cost.

The following additional assumptions and inclusions are inherent in the capital cost estimates:

- Location of the plant site in terrain consisting of low rolling hills and requiring a minimum of blasting and rock excavation

- Availability of access roads to the project site suitable for personnel and equipment transportation

- Base wage rates for construction crafts of $10.00 per hour

- Stabilized roads within the uranium facility are included in the estimate

POTENTIAL ADDITIONAL PRODUCTS

In addition to the products included in the outlined objectives of this study, a number of potentially important additional products merit serious study to determine the feasibility of their inclusion in the production process. These materials include thorium (10 ppm in the original shale), molybdenum (1,200 ppm), vanadium (760 ppm), nickel (530 ppm), cobalt (230 ppm), and alumina (variable, but maybe 10 percent Al_2O_3, or greater), Mutschler, *et*. *al*. [1976]. During acid leaching of the roasted shale, it is believed that substantial amounts of all these metals will dissolve. Techniques such as solvent extraction, chemical processing, and electrowinning for selectively recovering such elements from the leach liquors are already known and should not add greatly to the capital and operating costs. Also, additional work on the recovery of alumina from leach liquors is in progress.

Based upon meager information on somewhat similar material and the assumption that 60 percent of the thorium, molybdenum, nickel, and cobalt, and 40 percent of the vanadium can be recovered from the roasted ore, the potential monetary contribution of these metals at present metal prices to the economy of the process is indicated in Case 1-1 through 1-9 of the economic evaluation.

The potential outlined in Case 1 suggests further study of the feasibility of recovering these products from the roasted shale. Although technology is already available for recovering the metals listed, detailed research and investigation would be required to determine optimum flowsheets and to provide firm recovery data. Furthermore, the market reaction to the offering of large amounts of low-consumption metals would also require thorough evaluation. Table V-2 is presented as a guide to the current use of potential co-product metals.

The sulfur, carbon, and small amount of hydrogen present in the shale discharged from the hydroretort represent a large energy potential that can strongly contribute to the overall process economy by acting as a substitute for fuel oil otherwise needed for process steam and power. By recovering surplus heat in the gases evolved from the roasting furnaces much of the fuel oil requirement for the power steam boilers probably can be eliminated. Each ton of hydroretorted shale contains a calculated 1.3 million BTU. Recovery of this heat in waste heat boilers at an estimated 70 percent efficiency should enable the release of an additional 15,500 barrels of syncrude oil per day for marketing.

TABLE V-2. RECENT PRODUCTION [a] OF U, V, Co, Ni, Mo, Th

Metal	World	U. S.
Uranium, short tons U_3O_8	24,176 (1974) [b]	14,940 (1977) [f]
Vanadium, short tons V	31,241 (1976) [c]	6,197 (1976) [c]
Cobalt, short tons Co	39,000 (1976) [d]	-
Nickel, metric tons Ni	697,700 (1976) [d]	15,600 (1976) [d]
Molybdenum, thousand pounds	190,185 (1976) [d]	113,000 (1976) [d]
Thorium, short tons Th	1,014 (1973) [e]	

[a] References do not always agree on these production figures.
[b] U.S. Bureau of Mines [1974]
[c] U.S. Bureau of Mines, Mineral Commodity Profile MCP-8, Dec. 1977
[d] American Metal Market, Metal Statistics [1977]
[e] U.S. Bureau of Mines [1975]
[f] GJO-100 (78)

CHATTANOOGA SHALE PROJECT
DEPARTMENT OF ENERGY
MSE JOB 557

CASE 1-1 - 55 PPM URANIUM, CURRENT OIL AND URANIUM PRICES
BYPRODUCT METAL CREDITS INCLUDED

PRODUCT SALES SUMMARY

					$MM/YR
SYNCRUDE	55329	BL/DY	@ 14.00	$/BBL	271.1
URANIUM	2310000	LB/YR	@ 50.12	$/LB	115.8
SULFUR	2050	LT/DY	@ 40.00	$/LT	28.7
AMMONIA	490	ST/DY	@120.00	$/ST	20.6
VANADIUM	21280000	LB/YR	@ 4.91	$/LB	104.5
COBALT	8050000	LB/YR	@ 8.54	$/LB	68.8
NICKEL	18550000	LB/YR	@ 2.13	$/LB	39.5
MOLYBDENUM	7000000	LB/YR	@ 4.50	$/LB	31.5
THORIUM	350000	LB/YR	@ 2.00	$/LB	.7
ELECTRICITY	162000	KW/HR	@ .02	$/KWH	27.2
TOTAL SALES REVENUE					708.4

YEAR	-1	-2	-3	1	2	10	20	TOTAL
TOTAL SALES	0	0	0	708	708	708	708	14168
TOTAL OPERATING COST	0	0	0	416	416	416	416	8317
GROSS PROFIT	0	0	0	293	293	293	293	5851
LESS DEPRECIATION	0	0	0	201	172	175	18	2262
NET BEFORE DEPLETION	0	0	0	91	121	118	274	3589
LESS DEPLETION	0	0	0	46	60	59	126	1714
TAXABLE INCOME	0	0	0	46	60	59	140	1874
INVESTMENT TAX CRED.	0	0	0	11	14	14	0	184
INCOME TAX	0	0	0	28	37	36	82	1087
NET INCOME	0	0	0	29	38	37	66	972
PLUS DEPRECIATION	0	0	0	201	172	175	18	2262
PLUS DEPLETION	0	0	0	46	60	59	126	1714
GROSS CASH FLOW	0	0	0	275	270	271	210	4948
WORKING CAPITAL	0	0	104	0	0	0	¯104	0
CAPITAL INVESTMENT	356	730	770	103	22	15	3	2303
NET CASH FLOW	¯356	¯730	¯874	172	248	256	311	2645
CUM. NET CASH FLOW	¯356	¯1086	¯1960	¯1788	¯1541	471	2645	

RETURN ON INVESTMENT 8.87 %

PAYOUT PERIOD 8.07 YEARS

CHATTANOOGA SHALE PROJECT
DEPARTMENT OF ENERGY
MSE JOB 557

CASE 1-2 - 85 PPM URANIUM, CURRENT OIL AND URANIUM PRICES
BYPRODUCT METAL CREDITS INCLUDED

PRODUCT SALES SUMMARY

						$MM/YR
SYNCRUDE	55329	BL/DY	@	14.00	$/BBL	271.1
URANIUM	3570000	LB/YR	@	50.12	$/LB	178.9
SULFUR	2050	LT/DY	@	40.00	$/LT	28.7
AMMONIA	490	ST/DY	@	120.00	$/ST	20.6
VANADIUM	21280000	LB/YR	@	4.91	$/LB	104.5
COBALT	8050000	LB/YR	@	8.54	$/LB	68.8
NICKEL	18550000	LB/YR	@	2.13	$/LB	39.5
MOLYBDENUM	7000000	LB/YR	@	4.50	$/LB	31.5
THORIUM	350000	LB/YR	@	2.00	$/LB	.7
ELECTRICITY	162000	KW/HR	@	.02	$/KWH	27.2
TOTAL SALES REVENUE						771.5

YEAR	-1	-2	-3	1	2	10	20	TOTAL
TOTAL SALES	0	0	0	772	772	772	772	15431
TOTAL OPERATING COST	0	0	0	416	416	416	416	8317
GROSS PROFIT	0	0	0	356	356	356	356	7114
LESS DEPRECIATION	0	0	0	201	172	175	18	2262
NET BEFORE DEPLETION	0	0	0	155	184	181	337	4852
LESS DEPLETION	0	0	0	77	92	90	140	2204
TAXABLE INCOME	0	0	0	77	92	90	197	2647
INVESTMENT TAX CRED.	0	0	0	19	22	1	0	184
INCOME TAX	0	0	0	47	56	52	105	1491
NET INCOME	0	0	0	48	58	39	92	1340
PLUS DEPRECIATION	0	0	0	201	172	175	18	2262
PLUS DEPLETION	0	0	0	77	92	90	140	2204
GROSS CASH FLOW	0	0	0	327	321	304	250	5807
WORKING CAPITAL	0	0	104	0	0	0	¯104	0
CAPITAL INVESTMENT	356	730	770	103	22	15	3	2303
NET CASH FLOW	¯356	¯730	¯874	223	299	290	351	3504
CUM. NET CASH FLOW	¯356	¯1086	¯1960	¯1737	¯1438	946	3504	

RETURN ON INVESTMENT 11.11 %

PAYOUT PERIOD 6.71 YEARS

CHATTANOOGA SHALE PROJECT
DEPARTMENT OF ENERGY
MSE JOB 557

CASE 1-3 - 55 PPM URANIUM, SYNCRUDE $14/BBL, ROI 20 PERCENT
BYPRODUCT METAL CREDITS INCLUDED

PRODUCT SALES SUMMARY

				$MM/YR
SYNCRUDE	55329	BL/DY	@ 14.00 $/BBL	271.1
URANIUM	2310000	LB/YR	@221.23 $/LB	511.0
SULFUR	2050	LT/DY	@ 40.00 $/LT	28.7
AMMONIA	490	ST/DY	@120.00 $/ST	20.6
VANADIUM	21280000	LB/YR	@ 4.91 $/LB	104.5
COBALT	8050000	LB/YR	@ 8.54 $/LB	68.8
NICKEL	18550000	LB/YR	@ 2.13 $/LB	39.5
MOLYBDENUM	7000000	LB/YR	@ 4.50 $/LB	31.5
THORIUM	350000	LB/YR	@ 2.00 $/LB	.7
ELECTRICITY	162000	KW/HR	@ .02 $/KWH	27.2

TOTAL SALES REVENUE 1103.6

YEAR	-1	-2	-3	1	2	10	20	TOTAL
TOTAL SALES	0	0	0	1104	1104	1104	1104	22073
TOTAL OPERATING COST	0	0	0	416	416	416	416	8317
GROSS PROFIT	0	0	0	688	688	688	688	13756
LESS DEPRECIATION	0	0	0	201	172	175	18	2262
NET BEFORE DEPLETION	0	0	0	487	516	513	670	11494
LESS DEPLETION	0	0	0	213	213	213	213	4266
TAXABLE INCOME	0	0	0	273	303	300	456	7228
INVESTMENT TAX CRED.	0	0	0	66	73	1	0	184
INCOME TAX	0	0	0	159	172	160	228	3765
NET INCOME	0	0	0	180	203	140	228	3647
PLUS DEPRECIATION	0	0	0	201	172	175	18	2262
PLUS DEPLETION	0	0	0	213	213	213	213	4266
GROSS CASH FLOW	0	0	0	595	588	529	460	10175
WORKING CAPITAL	0	0	104	0	0	0	¯104	0
CAPITAL INVESTMENT	356	730	770	103	22	15	3	2303
NET CASH FLOW	¯356	¯730	¯874	491	566	514	561	7873
CUM. NET CASH FLOW	¯356	¯1086	¯1960	¯1469	¯903	3188	7873	

RETURN ON INVESTMENT 20.00 %

PAYOUT PERIOD 3.72 YEARS

CHATTANOOGA SHALE PROJECT
DEPARTMENT OF ENERGY
MSE JOB 557

CASE 1-4 - 55 PPM URANIUM, SYNCRUDE $14/BBL, ROI 15 PERCENT
BYPRODUCT METAL CREDITS INCLUDED

PRODUCT SALES SUMMARY

					$MM/YR
SYNCRUDE	55329	BL/DY	@ 14.00	$/BBL	271.1
URANIUM	2310000	LB/YR	@132.16	$/LB	305.3
SULFUR	2050	LT/DY	@ 40.00	$/LT	28.7
AMMONIA	490	ST/DY	@120.00	$/ST	20.6
VANADIUM	21280000	LB/YR	@ 4.91	$/LB	104.5
COBALT	8050000	LB/YR	@ 8.54	$/LB	68.8
NICKEL	18550000	LB/YR	@ 2.13	$/LB	39.5
MOLYBDENUM	7000000	LB/YR	@ 4.50	$/LB	31.5
THORIUM	350000	LB/YR	@ 2.00	$/LB	.7
ELECTRICITY	162000	KW/HR	@ .02	$/KWH	27.2
TOTAL SALES REVENUE					897.9

YEAR	-1	-2	-3	1	2	10	20	TOTAL
TOTAL SALES	0	0	0	898	898	898	898	17958
TOTAL OPERATING COST	0	0	0	416	416	416	416	8317
GROSS PROFIT	0	0	0	482	482	482	482	9641
LESS DEPRECIATION	0	0	0	201	172	175	18	2262
NET BEFORE DEPLETION	0	0	0	281	310	307	464	7379
LESS DEPLETION	0	0	0	140	155	154	168	3185
TAXABLE INCOME	0	0	0	140	155	154	296	4194
INVESTMENT TAX CRED.	0	0	0	34	37	1	0	184
INCOME TAX	0	0	0	86	95	89	152	2300
NET INCOME	0	0	0	88	97	66	144	2078
PLUS DEPRECIATION	0	0	0	201	172	175	18	2262
PLUS DEPLETION	0	0	0	140	155	154	168	3185
GROSS CASH FLOW	0	0	0	430	424	394	330	7525
WORKING CAPITAL	0	0	104	0	0	0	¯104	0
CAPITAL INVESTMENT	356	730	770	103	22	15	3	2303
NET CASH FLOW	¯356	¯730	¯874	326	402	380	431	5222
CUM. NET CASH FLOW	¯356	¯1086	¯1960	¯1634	¯1232	1844	5222	

RETURN ON INVESTMENT 15.00 %

PAYOUT PERIOD 5.07 YEARS

CHATTANOOGA SHALE PROJECT
DEPARTMENT OF ENERGY
MSE JOB 557

CASE 1-5 - 55 PPM URANIUM, SYNCRUDE $20/BBL, ROI 15 PERCENT
BYPRODUCT METAL CREDITS INCLUDED

PRODUCT SALES SUMMARY

					$MM/YR
SYNCRUDE	55329	BL/DY	@ 20.00	$/BBL	387.3
URANIUM	2310000	LB/YR	@ 82.03	$/LB	189.5
SULFUR	2050	LT/DY	@ 40.00	$/LT	28.7
AMMONIA	490	ST/DY	@120.00	$/ST	20.6
VANADIUM	21280000	LB/YR	@ 4.91	$/LB	104.5
COBALT	8050000	LB/YR	@ 8.54	$/LB	68.8
NICKEL	18550000	LB/YR	@ 2.13	$/LB	39.5
MOLYBDENUM	7000000	LB/YR	@ 4.50	$/LB	31.5
THORIUM	350000	LB/YR	@ 2.00	$/LB	.7
ELECTRICITY	162000	KW/HR	@ .02	$/KWH	27.2

TOTAL SALES REVENUE 898.3

YEAR	-1	-2	-3	1	2	10	20	TOTAL
TOTAL SALES	0	0	0	898	898	898	898	17966
TOTAL OPERATING COST	0	0	0	416	416	416	416	8317
GROSS PROFIT	0	0	0	482	482	482	482	9649
LESS DEPRECIATION	0	0	0	201	172	175	18	2262
NET BEFORE DEPLETION	0	0	0	281	311	308	464	7387
LESS DEPLETION	0	0	0	141	155	154	160	3123
TAXABLE INCOME	0	0	0	141	155	154	304	4264
INVESTMENT TAX CRED.	0	0	0	34	37	1	0	184
INCOME TAX	0	0	0	86	95	89	154	2321
NET INCOME	0	0	0	88	97	66	150	2127
PLUS DEPRECIATION	0	0	0	201	172	175	18	2262
PLUS DEPLETION	0	0	0	141	155	154	160	3123
GROSS CASH FLOW	0	0	0	430	424	395	328	7512
WORKING CAPITAL	0	0	104	0	0	0	¯104	0
CAPITAL INVESTMENT	356	730	770	103	22	15	3	2303
NET CASH FLOW	¯356	¯730	¯874	326	402	380	429	5210
CUM. NET CASH FLOW	¯356	¯1086	¯1960	¯1634	¯1232	1847	5210	

RETURN ON INVESTMENT 15.00 %

PAYOUT PERIOD 5.07 YEARS

CHATTANOOGA SHALE PROJECT
DEPARTMENT OF ENERGY
MSE JOB 557

CASE 1-6 - 55 PPM URANIUM, SYNCRUDE $20/BBL, ROI 20 PERCENT
BYPRODUCT METAL CREDITS INCLUDED

PRODUCT SALES SUMMARY

				$MM/YR
SYNCRUDE	55329 BL/DY	@ 20.00	$/BBL	387.3
URANIUM	2310000 LB/YR	@172.44	$/LB	398.3
SULFUR	2050 LT/DY	@ 40.00	$/LT	28.7
AMMONIA	490 ST/DY	@120.00	$/ST	20.6
VANADIUM	21280000 LB/YR	@ 4.91	$/LB	104.5
COBALT	8050000 LB/YR	@ 8.54	$/LB	68.8
NICKEL	18550000 LB/YR	@ 2.13	$/LB	39.5
MOLYBDENUM	7000000 LB/YR	@ 4.50	$/LB	31.5
THORIUM	350000 LB/YR	@ 2.00	$/LB	.7
ELECTRICITY	162000 KW/HR	@ .02	$/KWH	27.2

TOTAL SALES REVENUE 1107.1

YEAR	-1	-2	-3	1	2	10	20	TOTAL
TOTAL SALES	0	0	0	1107	1107	1107	1107	22143
TOTAL OPERATING COST	0	0	0	416	416	416	416	8317
GROSS PROFIT	0	0	0	691	691	691	691	13826
LESS DEPRECIATION	0	0	0	201	172	175	18	2262
NET BEFORE DEPLETION	0	0	0	490	519	516	673	11564
LESS DEPLETION	0	0	0	206	206	206	206	4119
TAXABLE INCOME	0	0	0	284	314	310	467	7445
INVESTMENT TAX CRED.	0	0	0	68	75	1	0	184
INCOME TAX	0	0	0	163	176	164	234	3851
NET INCOME	0	0	0	190	212	148	234	3778
PLUS DEPRECIATION	0	0	0	201	172	175	18	2262
PLUS DEPLETION	0	0	0	206	206	206	206	4119
GROSS CASH FLOW	0	0	0	597	590	529	458	10159
WORKING CAPITAL	0	0	104	0	0	0	¯104	0
CAPITAL INVESTMENT	356	730	770	103	22	15	3	2303
NET CASH FLOW	¯356	¯730	¯874	493	568	514	559	7856
CUM. NET CASH FLOW	¯356	¯1086	¯1960	¯1467	¯899	3187	7856	

RETURN ON INVESTMENT 20.00 %

PAYOUT PERIOD 3.72 YEARS

CHATTANOOGA SHALE PROJECT
DEPARTMENT OF ENERGY
MSE JOB 557

CASE 1-7 - 85 PPM URANIUM, SYNCRUDE $20/BBL, ROI 15 PERCENT
BYPRODUCT METAL CREDITS INCLUDED

PRODUCT SALES SUMMARY

					$MM/YR
SYNCRUDE	55329	BL/DY	@ 20.00	$/BBL	387.3
URANIUM	3570000	LB/YR	@ 53.08	$/LB	189.5
SULFUR	2050	LT/DY	@ 40.00	$/LT	28.7
AMMONIA	490	ST/DY	@120.00	$/ST	20.6
VANADIUM	21280000	LB/YR	@ 4.91	$/LB	104.5
COBALT	8050000	LB/YR	@ 8.54	$/LB	68.8
NICKEL	18550000	LB/YR	@ 2.13	$/LB	39.5
MOLYBDENUM	7000000	LB/YR	@ 4.50	$/LB	31.5
THORIUM	350000	LB/YR	@ 2.00	$/LB	.7
ELECTRICITY	162000	KW/HR	@ .02	$/KWH	27.2
TOTAL SALES REVENUE					898.3

YEAR	-1	-2	-3	1	2	10	20	TOTAL
TOTAL SALES	0	0	0	898	898	898	898	17966
TOTAL OPERATING COST	0	0	0	416	416	416	416	8317
GROSS PROFIT	0	0	0	482	482	482	482	9649
LESS DEPRECIATION	0	0	0	201	172	175	18	2262
NET BEFORE DEPLETION	0	0	0	281	311	308	464	7387
LESS DEPLETION	0	0	0	141	155	154	160	3123
TAXABLE INCOME	0	0	0	141	155	154	304	4264
INVESTMENT TAX CRED.	0	0	0	34	37	1	0	184
INCOME TAX	0	0	0	86	95	89	154	2321
NET INCOME	0	0	0	88	97	66	150	2127
PLUS DEPRECIATION	0	0	0	201	172	175	18	2262
PLUS DEPLETION	0	0	0	141	155	154	160	3123
GROSS CASH FLOW	0	0	0	430	424	395	328	7512
WORKING CAPITAL	0	0	104	0	0	0	-104	0
CAPITAL INVESTMENT	356	730	770	103	22	15	3	2303
NET CASH FLOW	-356	-730	-874	326	402	380	429	5210
CUM. NET CASH FLOW	-356	-1086	-1960	-1634	-1232	1847	5210	

RETURN ON INVESTMENT 15.00 %

PAYOUT PERIOD 5.07 YEARS

CHATTANOOGA SHALE PROJECT
DEPARTMENT OF ENERGY
MSE JOB 557

CASE 1-8 - 85 PPM URANIUM, SYNCRUDE $20/BBL, ROI 20 PERCENT
BYPRODUCT METAL CREDITS INCLUDED

PRODUCT SALES SUMMARY

					$MM/YR
SYNCRUDE	55329	BL/DY	@ 20.00	$/BBL	387.3
URANIUM	3570000	LB/YR	@111.58	$/LB	398.3
SULFUR	2050	LT/DY	@ 40.00	$/LT	28.7
AMMONIA	490	ST/DY	@120.00	$/ST	20.6
VANADIUM	21280000	LB/YR	@ 4.91	$/LB	104.5
COBALT	8050000	LB/YR	@ 8.54	$/LB	68.8
NICKEL	18550000	LB/YR	@ 2.13	$/LB	39.5
MOLYBDENUM	7000000	LB/YR	@ 4.50	$/LB	31.5
THORIUM	350000	LB/YR	@ 2.00	$/LB	.7
ELECTRICITY	162000	KW/HR	@ .02	$/KWH	27.2
TOTAL SALES REVENUE					1107.1

YEAR	-1	-2	-3	1	2	10	20	TOTAL
TOTAL SALES	0	0	0	1107	1107	1107	1107	22143
TOTAL OPERATING COST	0	0	0	416	416	416	416	8317
GROSS PROFIT	0	0	0	691	691	691	691	13826
LESS DEPRECIATION	0	0	0	201	172	175	18	2262
NET BEFORE DEPLETION	0	0	0	490	519	516	673	11564
LESS DEPLETION	0	0	0	206	206	206	206	4119
TAXABLE INCOME	0	0	0	284	314	310	467	7445
INVESTMENT TAX CRED.	0	0	0	68	75	1	0	184
INCOME TAX	0	0	0	163	176	164	234	3851
NET INCOME	0	0	0	190	212	148	234	3778
PLUS DEPRECIATION	0	0	0	201	172	175	18	2262
PLUS DEPLETION	0	0	0	206	206	206	206	4119
GROSS CASH FLOW	0	0	0	597	590	529	458	10159
WORKING CAPITAL	0	0	104	0	0	0	¯104	0
CAPITAL INVESTMENT	356	730	770	103	22	15	3	2303
NET CASH FLOW	¯356	¯730	¯874	493	568	514	559	7856
CUM. NET CASH FLOW	¯356	¯1086	¯1960	¯1467	¯899	3187	7856	

RETURN ON INVESTMENT 20.00 %

PAYOUT PERIOD 3.72 YEARS

CHATTANOOGA SHALE PROJECT
DEPARTMENT OF ENERGY
MSE JOB 557

CASE 1-9 - 55 PPM URANIUM, SYNCRUDE $20/BBL, URANIUM $50.12/LB
BYPRODUCT METAL CREDITS INCLUDED

PRODUCT SALES SUMMARY

						$MM/YR
SYNCRUDE	55329	BL/DY	@	20.00	$/BBL	387.3
URANIUM	2310000	LB/YR	@	50.12	$/LB	115.8
SULFUR	2050	LT/DY	@	40.00	$/LT	28.7
AMMONIA	490	ST/DY	@	120.00	$/ST	20.6
VANADIUM	21280000	LB/YR	@	4.91	$/LB	104.5
COBALT	8050000	LB/YR	@	8.54	$/LB	68.8
NICKEL	18550000	LB/YR	@	2.13	$/LB	39.5
MOLYBDENUM	7000000	LB/YR	@	4.50	$/LB	31.5
THORIUM	350000	LB/YR	@	2.00	$/LB	.7
ELECTRICITY	162000	KW/HR	@	.02	$/KWH	27.2

TOTAL SALES REVENUE 824.6

YEAR	-1	-2	-3	1	2	10	20	TOTAL
TOTAL SALES	0	0	0	825	825	825	825	16491
TOTAL OPERATING COST	0	0	0	416	416	416	416	8317
GROSS PROFIT	0	0	0	409	409	409	409	8175
LESS DEPRECIATION	0	0	0	201	172	175	18	2262
NET BEFORE DEPLETION	0	0	0	208	237	234	390	5912
LESS DEPLETION	0	0	0	104	118	117	144	2551
TAXABLE INCOME	0	0	0	104	118	117	247	3362
INVESTMENT TAX CRED.	0	0	0	25	28	1	0	184
INCOME TAX	0	0	0	64	73	68	127	1849
NET INCOME	0	0	0	65	74	50	120	1697
PLUS DEPRECIATION	0	0	0	201	172	175	18	2262
PLUS DEPLETION	0	0	0	104	118	117	144	2551
GROSS CASH FLOW	0	0	0	370	364	342	282	6510
WORKING CAPITAL	0	0	104	0	0	0	-104	0
CAPITAL INVESTMENT	356	730	770	103	22	15	3	2303
NET CASH FLOW	-356	-730	-874	266	342	328	383	4207
CUM. NET CASH FLOW	-356	-1086	-1960	-1694	-1352	1323	4207	

RETURN ON INVESTMENT 12.80 %

PAYOUT PERIOD 5.80 YEARS

CASH FLOW ANALYSIS INPUT DATA

TOTAL COST SUMMARY

CAPITAL COST SUMMARY	$MM
TOTAL MINE CAPITAL	301.02
BACKFILLING EQUIP.	54.56
TOTAL SYNCRUDE PLANT	648.20
TOTAL URANIUM PLANT	394.40
BY-PRODUCT PLANT	175.60
POWER PLANT EXPANS.	35.00
ACID PLANT	144.00
TAILINGS DISPOSAL	52.20
TAILINGS DAM	114.00
CONTINGENCY @ 20%	383.79
TOTAL CAPITAL COST	2302.77

OPERATING COST SUMMARY	$MM/YR
DIRECT OPERATING COSTS	
MINING, LAND, ROYALTY	168.70
SYNCRUDE PLANT	44.61
ROASTING SECTION	17.46
GRINDING SECTION	8.29
ACID PLANT	16.70
LEACHING SECTION	12.05
S-X PROD SECTION	5.30
AUXILLARY FAC.	4.81
POWER SECTION	2.15
TAILINGS DISPOSAL	20.22
BY-PRODUCT SECTION	21.21
TOTAL DIRECT COST	321.50
INDIRECT COSTS	
LOCAL TAXES & INSURANCE 2.7% OF CAPITAL	62.17
GENERAL AND ADMINISTRATION 10% OF DIRECT	32.15
TOTAL INDIRECT COST	94.32
TOTAL OPERATING COST	415.83

CAPITAL OUTLAY SCHEDULE

YEAR	-1	-2	-3	1	2	3-5
MOBILE EQUIPMENT	5.3	5.2	2.9	35.1	2.7	20.4
MISCELLANEOUS	.8	5.6	10.9	18.1	10.0	5.0
MINE DEVELOPMENT	1.0	17.7	15.3	.0	.0	.0
TOTAL MINE CAPITAL	7.1	28.5	29.1	53.2	12.7	25.4
BACKFILLING EQUIP.	.0	.0	27.3	27.3	.0	.0
TOTAL SYNCRUDE PLANT	129.6	259.3	259.3	.0	.0	.0
ROASTING PLANT	33.9	67.7	67.7	.0	.0	.0
GRINDING PLANT	6.0	12.1	12.1	.0	.0	.0
LEACHING AND CCD	13.5	26.9	26.9	.0	.0	.0
SOL. EXT. AND PROD	8.8	17.6	17.6	.0	.0	.0
AUXILLARY FAC.	16.7	33.5	33.5	.0	.0	.0
TOTAL URANIUM PLANT	78.9	157.8	157.8	.0	.0	.0
BY-PRODUCT PLANT	35.1	70.2	70.2	.0	.0	.0
POWER PLANT EXPANS.	7.0	14.0	14.0	.0	.0	.0
ACID PLANT	28.8	57.6	57.6	.0	.0	.0
TAILINGS DISPOSAL	10.4	20.9	20.9	.0	.0	.0
TAILINGS DAM	.0	.0	5.7	5.7	5.7	17.1
CONTINGENCY @ 20%	59.4	121.7	128.4	17.2	3.7	8.5
TOTAL CAPITAL OUTLAY	356.4	730.0	770.2	103.5	22.1	51.0

YEAR	6-8	9-11	12-14	15-17	18-20	TOTAL
MOBILE EQUIPMENT	17.2	36.0	26.6	32.5	16.4	200.4
MISCELLANEOUS	4.2	4.5	3.4	1.9	2.2	66.6
MINE DEVELOPMENT	.0	.0	.0	.0	.0	34.0
TOTAL MINE CAPITAL	21.4	40.5	30.0	34.5	18.6	301.0
BACKFILLING EQUIP.	.0	.0	.0	.0	.0	54.6
TOTAL SYNCRUDE PLANT	.0	.0	.0	.0	.0	648.2
ROASTING PLANT	.0	.0	.0	.0	.0	169.3
GRINDING PLANT	.0	.0	.0	.0	.0	30.2
LEACHING AND CCD	.0	.0	.0	.0	.0	67.3
SOL. EXT. AND PROD	.0	.0	.0	.0	.0	43.9
AUXILLARY FAC.	.0	.0	.0	.0	.0	83.7
TOTAL URANIUM PLANT	.0	.0	.0	.0	.0	394.4
BY-PRODUCT PLANT	.0	.0	.0	.0	.0	175.6
POWER PLANT EXPANS.	.0	.0	.0	.0	.0	35.0
ACID PLANT	.0	.0	.0	.0	.0	144.0
TAILINGS DISPOSAL	.0	.0	.0	.0	.0	52.2
TAILINGS DAM	17.1	17.1	17.1	17.1	11.4	114.0
CONTINGENCY @ 20%	7.7	11.5	9.4	10.3	6.0	383.8
TOTAL CAPITAL OUTLAY	46.2	69.2	56.5	61.9	35.9	2302.8

ANNUAL DIRECT OPERATING COSTS

MINING

100000 TPD

OPERATING COST	$MM/YR	$/TON
MINING COSTS AT $2.336/TON	81.760	2.336
BACKFILLING COSTS AT $0.484/TON	16.940	.484
LAND AND ROYALTY	70.000	2.000
TOTAL DIRECT OPERATING COST	168.700	4.820

ANNUAL DIRECT OPERATING COSTS

SYNCRUDE PLANT

100000 TPD

LABOR	$MM/YR	$/TON
OPERATING LABOR	3.490	.100
MAINTENANCE LABOR AT 1.5% OF TPI	11.668	.333
SUPERVISION 15% OF LABOR COST	2.274	.065
OVERHEAD 60% OF TOTAL LABOR COST	10.459	.299
MATERIALS		
OPERATING, 30% OF OPERATING LABOR	1.047	.030
MAINTENANCE 1.5% OF TPI	11.668	.333
WATER AT $0.10 PER 1000 GALLONS	.288	.008
CATALYSTS AND CHEMICALS	3.714	.106
TOTAL DIRECT OPERATING COST	44.607	1.274

ANNUAL DIRECT OPERATING COSTS

ROASTING SECTION

80000 TPD

	$MM/YR	$/TON
LABOR		
OPERATING LABOR	1.760	.063
MAINTENANCE LABOR AT 1.5% OF TPI	3.047	.109
SUPERVISION 15% OF LABOR COST	.721	.026
OVERHEAD 60% OF TOTAL LABOR COST	3.317	.118
MATERIALS		
OPERATING, 30% OF OPERATING LABOR	.528	.019
MAINTENANCE 1.5% OF TPI	3.047	.109
POWER 9 KWH/TON (40,000HP)	5.040	.180
TOTAL DIRECT OPERATING COST	17.461	.624

ANNUAL DIRECT OPERATING COSTS

GRINDING SECTION

80000 TPD

	$MM/YR	$/TON
LABOR		
OPERATING LABOR	.590	.021
MAINTENANCE LABOR AT 1.5% OF TPI	.544	.019
SUPERVISION 15% OF LABOR COST	.170	.006
OVERHEAD 60% OF TOTAL LABOR COST	.782	.028
MATERIALS		
OPERATING, 30% OF OPERATING LABOR	.177	.006
MAINTENANCE 1.5% OF TPI	.544	.019
GRINDING BALLS 0.2 LBS/TON AT $.18/LB	1.008	.036
GRINDING LINERS 0.02 LBS/TON AT $.40/LB	.224	.008
POWER 7.6 KWH/TON AT $0.02/KWH	4.256	.152
TOTAL DIRECT OPERATING COST	8.294	.296

ANNUAL DIRECT OPERATING COSTS

SULFURIC ACID PLANT

8000 TPD

	$MM/YR	$/TON
LABOR		
OPERATING LABOR	.530	.189
MAINTENANCE LABOR AT 1.5% OF TPI	2.592	.926
SUPERVISION 15% OF LABOR COST	.468	.167
OVERHEAD 60% OF TOTAL LABOR COST	2.154	.769
MATERIALS		
OPERATING, 30% OF OPERATING LABOR	.159	.057
MAINTENANCE 1.5% OF TPI	2.592	.926
FUEL	.290	.104
REAGENTS	.190	.068
MISCELLANEOUS	.280	.100
POWER 130 KWH/TON AT $0.02/KWH	7.280	2.600
WATER 600 GAL/TON H2SO4 AT $0.10/1000 GA	.168	.060
TOTAL DIRECT OPERATING COST	16.703	5.966

ANNUAL DIRECT OPERATING COSTS

LEACHING AND CCD SECTION

80000 TPD

	$MM/YR	$/TON
LABOR		
OPERATING LABOR	.590	.021
MAINTENANCE LABOR AT 1.5% OF TPI	1.211	.043
SUPERVISION 15% OF LABOR COST	.270	.010
OVERHEAD 60% OF TOTAL LABOR COST	1.243	.044
MATERIALS		
OPERATING, 30% OF OPERATING LABOR	.177	.006
MAINTENANCE 1.5% OF TPI	1.211	.043
SULFURIC ACID 200LB/TON AT NO COST	.000	.000
FLOCCULANT - 0.2 LB/TON	5.600	.200
POWER 6390 KW	1.074	.038
WATER 240 GAL/TON AT $0.10/1000	.672	.024
TOTAL DIRECT OPERATING COST	12.049	.430

ANNUAL DIRECT OPERATING COSTS

SOLVENT EXTRACTION AND PRODUCT SECTION

80000 TPD

	$MM/YR	$/TON
LABOR		
OPERATING LABOR	.674	.024
MAINTENANCE LABOR AT 1.5% OF TPI	.790	.028
SUPERVISION 15% OF LABOR COST	.220	.008
OVERHEAD 60% OF TOTAL LABOR COST	1.010	.036
MATERIALS		
OPERATING, 30% OF OPERATING LABOR	.202	.007
MAINTENANCE 1.5% OF TPI	.790	.028
SOLVENT LOSSES	.610	.022
REAGENTS	.506	.018
POWER	.500	.018
TOTAL DIRECT OPERATING COST	5.303	.189

ANNUAL DIRECT OPERATING COSTS

AUXILLARY FACILLITIES

80000 TPD

	$MM/YR	$/TON
LABOR		
OPERATING LABOR	.246	.009
MAINTENANCE LABOR AT 1.5% OF TPI	1.507	.054
SUPERVISION 15% OF LABOR COST	.263	.009
OVERHEAD 60% OF TOTAL LABOR COST	1.209	.043
MATERIALS		
OPERATING, 30% OF OPERATING LABOR	.074	.003
MAINTENANCE 1.5% OF TPI	1.507	.054
TOTAL DIRECT OPERATING COST	4.805	.172

ANNUAL DIRECT OPERATING COSTS

EXPANDED POWER GENERATION SECTION

162 MWH

	$MM/YR	$/MWH
LABOR		
OPERATING LABOR	.168	.006
MAINTENANCE LABOR AT 1.5% OF TPI	.630	.023
SUPERVISION 15% OF LABOR COST	.120	.004
OVERHEAD 60% OF TOTAL LABOR COST	.551	.020
MATERIALS		
OPERATING, 30% OF OPERATING LABOR	.050	.002
MAINTENANCE 1.5% OF TPI	.630	.023
TOTAL DIRECT OPERATING COST	2.149	1.579

ANNUAL DIRECT OPERATING COSTS

TAILINGS DISPOSAL

80000 TPD

	$MM/YR	$/TON
LABOR		
OPERATING LABOR	.309	.011
MAINTENANCE LABOR AT 1.5% OF TPI	.940	.034
SUPERVISION 15% OF LABOR COST	.187	.007
OVERHEAD 60% OF TOTAL LABOR COST	.862	.031
MATERIALS		
OPERATING, 30% OF OPERATING LABOR	.093	.003
MAINTENANCE 1.5% OF TPI	.940	.034
LIMESTONE — 2,800,000 T/YR AT $5/TON	14.000	.500
GRINDING BALLS 2 LB/T AT $0.18/LB	1.008	.036
MILL LINERS 0.2 LB/T AT $0.40/LB	.224	.008
POWER	1.510	.054
WATER	.149	.005
TOTAL DIRECT OPERATING COST	20.221	.722

ANNUAL DIRECT OPERATING COSTS

BY PRODUCT PLANT

80000 TPD

	$MM/YR	$/TON
LABOR		
OPERATING LABOR	2.696	.096
MAINTENANCE LABOR AT 1.5% OF TPI	3.161	.113
SUPERVISION 15% OF LABOR COST	.879	.031
OVERHEAD 60% OF TOTAL LABOR COST	4.041	.144
MATERIALS		
OPERATING, 30% OF OPERATING LABOR	.809	.029
MAINTENANCE 1.5% OF TPI	3.161	.113
SOLVENT LOSSES	2.440	.087
REAGENTS	2.024	.072
POWER	2.000	.071
TOTAL DIRECT OPERATING COST	21.210	.758

CHATTANOOGA SHALE PROJECT
DEPARTMENT OF ENERGY
MSE JOB 557

CASE 2-1 - 55 PPM URANIUM, CURRENT OIL AND URANIUM PRICES
NO BYPRODUCT METAL CREDITS

PRODUCT SALES SUMMARY

			$MM/YR
SYNCRUDE	55329 BL/DY	@ 14.00 $/BBL	271.1
URANIUM	2310000 LB/YR	@ 50.12 $/LB	115.8
SULFUR	2050 LT/DY	@ 40.00 $/LT	28.7
AMMONIA	490 ST/DY	@120.00 $/ST	20.6
ELECTRICITY	162000 KW/HR	@ .02 $/KWH	27.2
TOTAL SALES REVENUE			463.4

YEAR	-1	-2	-3	1	2	10	20	TOTAL
TOTAL SALES	0	0	0	463	463	463	463	9268
TOTAL OPERATING COST	0	0	0	387	387	387	387	7736
GROSS PROFIT	0	0	0	77	77	77	77	1532
LESS DEPRECIATION	0	0	0	184	154	157	18	2052
NET BEFORE DEPLETION	0	0	0	¯107	¯78	¯81	58	¯520
LESS DEPLETION	0	0	0	0	0	0	29	227
TAXABLE INCOME	0	0	0	¯107	¯78	¯81	29	¯747
INVESTMENT TAX CRED.	0	0	0	0	0	0	7	55
INCOME TAX	0	0	0	¯53	¯39	¯40	18	¯348
NET INCOME	0	0	0	¯53	¯39	¯40	18	¯345
PLUS DEPRECIATION	0	0	0	184	154	157	18	2052
PLUS DEPLETION	0	0	0	0	0	0	29	227
GROSS CASH FLOW	0	0	0	130	115	117	66	1934
WORKING CAPITAL	0	0	97	0	0	0	¯97	0
CAPITAL INVESTMENT	314	646	686	103	22	15	3	2092
NET CASH FLOW	¯314	¯646	¯783	27	93	102	159	¯158
CUM. NET CASH FLOW	¯314	¯960	¯1742	¯1716	¯1623	¯845	¯158	[illegible]

RETURN ON INVESTMENT ¯.87 %

PAYOUT PERIOD GREATER THAN 23.00 YEARS

CHATTANOOGA SHALE PROJECT
DEPARTMENT OF ENERGY
MSE JOB 557

CASE 2-2 - 85 PPM URANIUM, CURRENT OIL AND URANIUM PRICES
NO BYPRODUCT METAL CREDITS

PRODUCT SALES SUMMARY

						$MM/YR
SYNCRUDE	55329	BL/DY	@	14.00	$/BBL	271.1
URANIUM	3570000	LB/YR	@	50.12	$/LB	178.9
SULFUR	2050	LT/DY	@	40.00	$/LT	28.7
AMMONIA	490	ST/DY	@	120.00	$/ST	20.6
ELECTRICITY	162000	KW/HR	@	.02	$/KWH	27.2
TOTAL SALES REVENUE						526.5

YEAR	-1	-2	-3	1	2	10	20	TOTAL
TOTAL SALES	0	0	0	527	527	527	527	10531
TOTAL OPERATING COST	0	0	0	387	387	387	387	7736
GROSS PROFIT	0	0	0	140	140	140	140	2795
LESS DEPRECIATION	0	0	0	184	154	157	18	2052
NET BEFORE DEPLETION	0	0	0	¯44	¯15	¯18	121	743
LESS DEPLETION	0	0	0	0	0	0	61	480
TAXABLE INCOME	0	0	0	¯44	¯15	¯18	61	263
INVESTMENT TAX CRED.	0	0	0	0	0	0	15	115
INCOME TAX	0	0	0	¯22	¯7	¯9	37	186
NET INCOME	0	0	0	¯22	¯7	¯9	38	192
PLUS DEPRECIATION	0	0	0	184	154	157	18	2052
PLUS DEPLETION	0	0	0	0	0	0	61	480
GROSS CASH FLOW	0	0	0	162	147	149	117	2724
WORKING CAPITAL	0	0	97	0	0	0	¯97	0
CAPITAL INVESTMENT	314	646	686	103	22	15	3	2092
NET CASH FLOW	¯314	¯646	¯783	58	125	134	211	631
CUM. NET CASH FLOW	¯314	¯960	¯1742	¯1684	¯1559	¯529	631	

RETURN ON INVESTMENT 2.85 %

PAYOUT PERIOD 14.66 YEARS

CHATTANOOGA SHALE PROJECT
DEPARTMENT OF ENERGY
MSE JOB 557

CASE 2-3 - 55 PPM URANIUM, SYNCRUDE $14/BBL, ROI 20 PERCENT
NO BYPRODUCT METAL CREDITS

PRODUCT SALES SUMMARY

			$MM/YR
SYNCRUDE	55329 BL/DY	@ 14.00 $/BBL	271.1
URANIUM	2310000 LB/YR	@283.02 $/LB	653.8
SULFUR	2050 LT/DY	@ 40.00 $/LT	28.7
AMMONIA	490 ST/DY	@120.00 $/ST	20.6
ELECTRICITY	162000 KW/HR	@ .02 $/KWH	27.2

TOTAL SALES REVENUE 1001.4

YEAR	-1	-2	-3	1	2	10	20	TOTAL
TOTAL SALES	0	0	0	1001	1001	1001	1001	20028
TOTAL OPERATING COST	0	0	0	387	387	387	387	7736
GROSS PROFIT	0	0	0	615	615	615	615	12292
LESS DEPRECIATION	0	0	0	184	154	157	18	2052
NET BEFORE DEPLETION	0	0	0	431	460	457	596	10240
LESS DEPLETION	0	0	0	191	191	191	191	3816
TAXABLE INCOME	0	0	0	240	269	266	406	6424
INVESTMENT TAX CRED.	0	0	0	58	65	1	0	167
INCOME TAX	0	0	0	140	154	143	203	3349
NET INCOME	0	0	0	158	181	125	203	3242
PLUS DEPRECIATION	0	0	0	184	154	157	18	2052
PLUS DEPLETION	0	0	0	191	191	191	191	3816
GROSS CASH FLOW	0	0	0	532	526	473	412	9110
WORKING CAPITAL	0	0	97	0	0	0	¯97	0
CAPITAL INVESTMENT	314	646	686	103	22	15	3	2092
NET CASH FLOW	¯314	¯646	¯783	429	504	458	506	7018
CUM. NET CASH FLOW	¯314	¯960	¯1742	¯1314	¯810	2835	7018	

RETURN ON INVESTMENT 20.00 %

PAYOUT PERIOD 3.73 YEARS

CHATTANOOGA SHALE PROJECT
DEPARTMENT OF ENERGY
MSE JOB 557

CASE 2-4 - 55 PPM URANIUM, SYNCRUDE $14/BBL, ROI 15 PERCENT
NO BYPRODUCT METAL CREDITS

PRODUCT SALES SUMMARY

			$MM/YR
SYNCRUDE	55329 BL/DY	@ 14.00 $/BBL	271.1
URANIUM	2310000 LB/YR	@203.88 $/LB	471.0
SULFUR	2050 LT/DY	@ 40.00 $/LT	28.7
AMMONIA	490 ST/DY	@120.00 $/ST	20.6
ELECTRICITY	162000 KW/HR	@ .02 $/KWH	27.2

TOTAL SALES REVENUE 818.6

YEAR	-1	-2	-3	1	2	10	20	TOTAL
TOTAL SALES	0	0	0	819	819	819	819	16371
TOTAL OPERATING COST	0	0	0	387	387	387	387	7736
GROSS PROFIT	0	0	0	432	432	432	432	8635
LESS DEPRECIATION	0	0	0	184	154	157	18	2052
NET BEFORE DEPLETION	0	0	0	248	277	274	413	6584
LESS DEPLETION	0	0	0	124	139	137	151	2849
TAXABLE INCOME	0	0	0	124	139	137	263	3735
INVESTMENT TAX CRED.	0	0	0	30	33	1	0	167
INCOME TAX	0	0	0	76	85	79	135	2051
NET INCOME	0	0	0	78	87	59	128	1851
PLUS DEPRECIATION	0	0	0	184	154	157	18	2052
PLUS DEPLETION	0	0	0	124	139	137	151	2849
GROSS CASH FLOW	0	0	0	385	380	353	297	6752
WORKING CAPITAL	0	0	97	0	0	0	¯97	0
CAPITAL INVESTMENT	314	646	686	103	22	15	3	2092
NET CASH FLOW	¯314	¯646	¯783	282	358	339	391	4660
CUM. NET CASH FLOW	¯314	¯960	¯1742	¯1461	¯1103	1639	4660	

RETURN ON INVESTMENT 15.00 %

PAYOUT PERIOD 5.08 YEARS

CHATTANOOGA SHALE PROJECT
DEPARTMENT OF ENERGY
MSE JOB 557

CASE 2-5 - 55 PPM URANIUM, SYNCRUDE $20/BBL, ROI 20 PERCENT
NO BYPRODUCT METAL CREDITS

PRODUCT SALES SUMMARY

				$MM/YR
SYNCRUDE	55329 BL/DY	@ 20.00	$/BBL	387.3
URANIUM	2310000 LB/YR	@234.23	$/LB	541.1
SULFUR	2050 LT/DY	@ 40.00	$/LT	28.7
AMMONIA	490 ST/DY	@120.00	$/ST	20.6
ELECTRICITY	162000 KW/HR	@ .02	$/KWH	27.2

TOTAL SALES REVENUE 1004.9

YEAR	-1	-2	-3	1	2	10	20	TOTAL
TOTAL SALES	0	0	0	1005	1005	1005	1005	20097
TOTAL OPERATING COST	0	0	0	387	387	387	387	7736
GROSS PROFIT	0	0	0	618	618	618	618	12361
LESS DEPRECIATION	0	0	0	184	154	157	18	2052
NET BEFORE DEPLETION	0	0	0	435	464	461	600	10310
LESS DEPLETION	0	0	0	183	183	183	183	3669
TAXABLE INCOME	0	0	0	251	280	277	416	6641
INVESTMENT TAX CRED.	0	0	0	60	67	1	0	167
INCOME TAX	0	0	0	144	158	146	208	3435
NET INCOME	0	0	0	167	190	132	208	3373
PLUS DEPRECIATION	0	0	0	184	154	157	18	2052
PLUS DEPLETION	0	0	0	183	183	183	183	3669
GROSS CASH FLOW	0	0	0	534	528	473	410	9094
WORKING CAPITAL	0	0	97	0	0	0	¯97	0
CAPITAL INVESTMENT	314	646	686	103	22	15	3	2092
NET CASH FLOW	¯314	¯646	¯783	431	506	458	504	7002
CUM. NET CASH FLOW	¯314	¯960	¯1742	¯1312	¯806	2834	7002	

RETURN ON INVESTMENT 20.00 %

PAYOUT PERIOD 3.73 YEARS

CHATTANOOGA SHALE PROJECT
DEPARTMENT OF ENERGY
MSE JOB 557

CASE 2-6 - 85 PPM URANIUM, SYNCRUDE $20/BBL, ROI 15 PERCENT
NO BYPRODUCT METAL CREDITS

PRODUCT SALES SUMMARY

			$MM/YR
SYNCRUDE	55329 BL/DY	@ 20.00 $/BBL	387.3
URANIUM	3570000 LB/YR	@ 99.48 $/LB	355.1
SULFUR	2050 LT/DY	@ 40.00 $/LT	28.7
AMMONIA	490 ST/DY	@120.00 $/ST	20.6
ELECTRICITY	162000 KW/HR	@ .02 $/KWH	27.2

TOTAL SALES REVENUE 818.9

YEAR	-1	-2	-3	1	2	10	20	TOTAL
TOTAL SALES	0	0	0	819	819	819	819	16379
TOTAL OPERATING COST	0	0	0	387	387	387	387	7736
GROSS PROFIT	0	0	0	432	432	432	432	8643
LESS DEPRECIATION	0	0	0	184	154	157	18	2052
NET BEFORE DEPLETION	0	0	0	249	278	275	414	6591
LESS DEPLETION	0	0	0	124	139	137	143	2787
TAXABLE INCOME	0	0	0	124	139	137	271	3804
INVESTMENT TAX CRED.	0	0	0	30	33	1	0	167
INCOME TAX	0	0	0	76	85	80	138	2071
NET INCOME	0	0	0	78	87	59	134	1900
PLUS DEPRECIATION	0	0	0	184	154	157	18	2052
PLUS DEPLETION	0	0	0	124	139	137	143	2787
GROSS CASH FLOW	0	0	0	386	380	354	295	6739
WORKING CAPITAL	0	0	97	0	0	0	¯97	0
CAPITAL INVESTMENT	314	646	686	103	22	15	3	2092
NET CASH FLOW	¯314	¯646	¯783	282	358	339	389	4647
CUM. NET CASH FLOW	¯314	¯960	¯1742	¯1460	¯1102	1642	4647	-

RETURN ON INVESTMENT 15.00 %

PAYOUT PERIOD 5.08 YEARS

CHATTANOOGA SHALE PROJECT
DEPARTMENT OF ENERGY
MSE JOB 557

CASE 2-7 - 55 PPM URANIUM, SYNCRUDE $15.45/BBL, ROI 20 PERCENT
NO BYPRODUCT METAL CREDITS

PRODUCT SALES SUMMARY

			$MM/YR
SYNCRUDE	55329 BL/DY	@ 15.45 $/BBL	299.2
URANIUM	2310000 LB/YR	@271.18 $/LB	626.4
SULFUR	2050 LT/DY	@ 40.00 $/LT	28.7
AMMONIA	490 ST/DY	@120.00 $/ST	20.6
ELECTRICITY	162000 KW/HR	@ .02 $/KWH	27.2
TOTAL SALES REVENUE			1002.1

YEAR	-1	-2	-3	1	2	10	20	TOTAL
TOTAL SALES	0	0	0	1002	1002	1002	1002	20042
TOTAL OPERATING COST	0	0	0	387	387	387	387	7736
GROSS PROFIT	0	0	0	615	615	615	615	12306
LESS DEPRECIATION	0	0	0	184	154	157	18	2052
NET BEFORE DEPLETION	0	0	0	432	461	458	597	10254
LESS DEPLETION	0	0	0	189	189	189	189	3780
TAXABLE INCOME	0	0	0	243	272	269	408	6474
INVESTMENT TAX CRED.	0	0	0	58	65	1	0	167
INCOME TAX	0	0	0	141	155	144	204	3369
NET INCOME	0	0	0	160	183	126	204	3273
PLUS DEPRECIATION	0	0	0	184	154	157	18	2052
PLUS DEPLETION	0	0	0	189	189	189	189	3780
GROSS CASH FLOW	0	0	0	533	526	473	412	9105
WORKING CAPITAL	0	0	97	0	0	0	¯97	0
CAPITAL INVESTMENT	314	646	686	103	22	15	3	2092
NET CASH FLOW	¯314	¯646	¯783	429	504	458	505	7013
CUM. NET CASH FLOW	¯314	¯960	¯1742	¯1313	¯809	2834	7013	

RETURN ON INVESTMENT 20.00 %

PAYOUT PERIOD 3.73 YEARS

CHATTANOOGA SHALE PROJECT
DEPARTMENT OF ENERGY
MSE JOB 557

CASE 2-8 - 55 PPM URANIUM, SYNCRUDE $20/BBL, URANIUM $50.12/LB
NO BYPRODUCT METAL CREDITS

PRODUCT SALES SUMMARY

				$MM/YR
SYNCRUDE	55329	BL/DY	@ 20.00 $/BBL	387.3
URANIUM	2310000	LB/YR	@ 50.12 $/LB	115.8
SULFUR	2050	LT/DY	@ 40.00 $/LT	28.7
AMMONIA	490	ST/DY	@120.00 $/ST	20.6
ELECTRICITY	162000	KW/HR	@ .02 $/KWH	27.2
TOTAL SALES REVENUE				579.6

YEAR	-1	-2	-3	1	2	10	20	TOTAL
TOTAL SALES	0	0	0	580	580	580	580	11592
TOTAL OPERATING COST	0	0	0	387	387	387	387	7736
GROSS PROFIT	0	0	0	193	193	193	193	3855
LESS DEPRECIATION	0	0	0	184	154	157	18	2052
NET BEFORE DEPLETION	0	0	0	9	38	35	175	1804
LESS DEPLETION	0	0	0	5	19	18	87	902
TAXABLE INCOME	0	0	0	5	19	18	87	902
INVESTMENT TAX CRED.	0	0	0	1	5	4	0	167
INCOME TAX	0	0	0	3	12	11	50	546
NET INCOME	0	0	0	3	12	11	37	523
PLUS DEPRECIATION	0	0	0	184	154	157	18	2052
PLUS DEPLETION	0	0	0	5	19	18	87	902
GROSS CASH FLOW	0	0	0	191	186	186	143	3476
WORKING CAPITAL	0	0	97	0	0	0	¯97	0
CAPITAL INVESTMENT	314	646	686	103	22	15	3	2092
NET CASH FLOW	¯314	¯646	¯783	88	164	172	236	1384
CUM. NET CASH FLOW	¯314	¯960	¯1742	¯1655	¯1491	¯155	1384	

RETURN ON INVESTMENT 5.63 %

PAYOUT PERIOD 10.91 YEARS

CHATTANOOGA SHALE PROJECT
DEPARTMENT OF ENERGY
MSE JOB 557

CASE 2-9 - 55 PPM URANIUM, SYNCRUDE $20/BBL, ROI 15 PERCENT
NO BYPRODUCT METAL CREDITS

PRODUCT SALES SUMMARY

					$MM/YR
SYNCRUDE	55329	BL/DY	@ 20.00	$/BBL	387.3
URANIUM	2310000	LB/YR	@153.74	$/LB	355.1
SULFUR	2050	LT/DY	@ 40.00	$/LT	28.7
AMMONIA	490	ST/DY	@120.00	$/ST	20.6
ELECTRICITY	162000	KW/HR	@ .02	$/KWH	27.2
TOTAL SALES REVENUE					818.9

YEAR	-1	-2	-3	1	2	10	20	TOTAL
TOTAL SALES	0	0	0	819	819	819	819	16379
TOTAL OPERATING COST	0	0	0	387	387	387	387	7736
GROSS PROFIT	0	0	0	432	432	432	432	8643
LESS DEPRECIATION	0	0	0	184	154	157	18	2052
NET BEFORE DEPLETION	0	0	0	249	278	275	414	6591
LESS DEPLETION	0	0	0	124	139	137	143	2787
TAXABLE INCOME	0	0	0	124	139	137	271	3804
INVESTMENT TAX CRED.	0	0	0	30	33	1	0	167
INCOME TAX	0	0	0	76	85	80	138	2071
NET INCOME	0	0	0	78	87	59	134	1900
PLUS DEPRECIATION	0	0	0	184	154	157	18	2052
PLUS DEPLETION	0	0	0	124	139	137	143	2787
GROSS CASH FLOW	0	0	0	386	380	354	295	6739
WORKING CAPITAL	0	0	97	0	0	0	-97	0
CAPITAL INVESTMENT	314	646	686	103	22	15	3	2092
NET CASH FLOW	-314	-646	-783	282	358	339	389	4647
CUM. NET CASH FLOW	-314	-960	-1742	-1460	-1102	1642	4647	

RETURN ON INVESTMENT 15.00 %

PAYOUT PERIOD 5.08 YEARS

CAPITAL OUTLAY SCHEDULE

YEAR	-1	-2	-3	1	2	3-5
MOBILE EQUIPMENT	5.3	5.2	2.9	35.1	2.7	20.4
MISCELLANEOUS	.8	5.6	10.9	18.1	10.0	5.0
MINE DEVELOPMENT	1.0	17.7	15.3	.0	.0	.0
TOTAL MINE CAPITAL	7.1	28.5	29.1	53.2	12.7	25.4
BACKFILLING EQUIP.	.0	.0	27.3	27.3	.0	.0
TOTAL SYNCRUDE PLANT	129.6	259.3	259.3	.0	.0	.0
ROASTING PLANT	33.9	67.7	67.7	.0	.0	.0
GRINDING PLANT	6.0	12.1	12.1	.0	.0	.0
LEACHING AND CCD	13.5	26.9	26.9	.0	.0	.0
SOL. EXT. AND PROD	8.8	17.6	17.6	.0	.0	.0
AUXILLARY FAC.	16.7	33.5	33.5	.0	.0	.0
TOTAL URANIUM PLANT	78.9	157.8	157.8	.0	.0	.0
POWER PLANT EXPANS.	7.0	14.0	14.0	.0	.0	.0
ACID PLANT	28.8	57.6	57.6	.0	.0	.0
TAILINGS DISPOSAL	10.4	20.9	20.9	.0	.0	.0
TAILINGS DAM	.0	.0	5.7	5.7	5.7	17.1
CONTINGENCY @ 20%	52.4	107.6	114.3	17.2	3.7	8.5
TOTAL CAPITAL OUTLAY	314.2	645.7	685.9	103.5	22.1	51.0

YEAR	6-8	9-11	12-14	15-17	18-20	TOTAL
MOBILE EQUIPMENT	17.2	36.0	26.6	32.5	16.4	200.4
MISCELLANEOUS	4.2	4.5	3.4	1.9	2.2	66.6
MINE DEVELOPMENT	.0	.0	.0	.0	.0	34.0
TOTAL MINE CAPITAL	21.4	40.5	30.0	34.5	18.6	301.0
BACKFILLING EQUIP.	.0	.0	.0	.0	.0	54.6
TOTAL SYNCRUDE PLANT	.0	.0	.0	.0	.0	648.2
ROASTING PLANT	.0	.0	.0	.0	.0	169.3
GRINDING PLANT	.0	.0	.0	.0	.0	30.2
LEACHING AND CCD	.0	.0	.0	.0	.0	67.3
SOL. EXT. AND PROD	.0	.0	.0	.0	.0	43.9
AUXILLARY FAC.	.0	.0	.0	.0	.0	83.7
TOTAL URANIUM PLANT	.0	.0	.0	.0	.0	394.4
POWER PLANT EXPANS.	.0	.0	.0	.0	.0	35.0
ACID PLANT	.0	.0	.0	.0	.0	144.0
TAILINGS DISPOSAL	.0	.0	.0	.0	.0	52.2
TAILINGS DAM	17.1	17.1	17.1	17.1	11.4	114.0
CONTINGENCY @ 20%	7.7	11.5	9.4	10.3	6.0	348.7
TOTAL CAPITAL OUTLAY	46.2	69.2	56.5	61.9	35.9	2092.0

CASH FLOW ANALYSIS INPUT DATA

TOTAL COST SUMMARY

CAPITAL COST SUMMARY	$MM
TOTAL MINE CAPITAL	301.02
BACKFILLING EQUIP.	54.56
TOTAL SYNCRUDE PLANT	648.20
TOTAL URANIUM PLANT	394.40
POWER PLANT EXPANS.	35.00
ACID PLANT	144.00
TAILINGS DISPOSAL	52.20
TAILINGS DAM	114.00
CONTINGENCY @ 20%	348.67
TOTAL CAPITAL COST	2092.05

OPERATING COST SUMMARY	$MM/YR
DIRECT OPERATING COSTS	
MINE	168.70
SYNCRUDE PLANT	44.61
ROASTING SECTION	17.46
GRINDING SECTION	8.29
ACID PLANT	16.70
LEACHING SECTION	12.05
S-X PROD SECTION	5.30
AUXILLARY FAC.	4.81
POWER SECTION	2.15
TAILINGS DISPOSAL	20.22
TOTAL DIRECT COST	300.29
INDIRECT COSTS	
LOCAL TAXES & INSURANCE 2.7% OF CAPITAL	56.49
GENERAL AND ADMINISTRATION 10% OF DIRECT	30.03
TOTAL INDIRECT COST	86.51
TOTAL OPERATING COST	386.81

ANNUAL DIRECT OPERATING COSTS

MINING

100000 TPD

OPERATING COST	$MM/YR	$/TON
MINING COSTS AT $2.336/TON	81.760	2.336
BACKFILLING COSTS AT $0.484/TON	16.940	.484
LAND AND ROYALTY	70.000	2.000
TOTAL DIRECT OPERATING COST	168.700	4.820

ANNUAL DIRECT OPERATING COSTS

SYNCRUDE PLANT

100000 TPD

LABOR	$MM/YR	$/TON
OPERATING LABOR	3.490	.100
MAINTENANCE LABOR AT 1.5% OF TPI	11.668	.333
SUPERVISION 15% OF LABOR COST	2.274	.065
OVERHEAD 60% OF TOTAL LABOR COST	10.459	.299
MATERIALS		
OPERATING, 30% OF OPERATING LABOR	1.047	.030
MAINTENANCE 1.5% OF TPI	11.668	.333
WATER AT $0.10 PER 1000 GALLONS	.288	.008
CATALYSTS AND CHEMICALS	3.714	.106
TOTAL DIRECT OPERATING COST	44.607	1.274

ANNUAL DIRECT OPERATING COSTS

ROASTING SECTION

80000 TPD

LABOR	$MM/YR	$/TON
OPERATING LABOR	1.760	.063
MAINTENANCE LABOR AT 1.5% OF TPI	3.047	.109
SUPERVISION 15% OF LABOR COST	.721	.026
OVERHEAD 60% OF TOTAL LABOR COST	3.317	.118
MATERIALS		
OPERATING, 30% OF OPERATING LABOR	.528	.019
MAINTENANCE 1.5% OF TPI	3.047	.109
POWER 9 KWH/TON (40,000HP)	5.040	.180
TOTAL DIRECT OPERATING COST	17.461	.624

ANNUAL DIRECT OPERATING COSTS

GRINDING SECTION

80000 TPD

LABOR	$MM/YR	$/TON
OPERATING LABOR	.590	.021
MAINTENANCE LABOR AT 1.5% OF TPI	.544	.019
SUPERVISION 15% OF LABOR COST	.170	.006
OVERHEAD 60% OF TOTAL LABOR COST	.782	.028
MATERIALS		
OPERATING, 30% OF OPERATING LABOR	.177	.006
MAINTENANCE 1.5% OF TPI	.544	.019
GRINDING BALLS 0.2 LBS/TON AT $.18/LB	1.008	.036
GRINDING LINERS 0.02 LBS/TON AT $.40/LB	.224	.008
POWER 7.6 KWH/TON AT $0.02/KWH	4.256	.152
TOTAL DIRECT OPERATING COST	8.294	.296

ANNUAL DIRECT OPERATING COSTS

SULFURIC ACID PLANT

8000 TPD

LABOR	$MM/YR	$/TON
OPERATING LABOR	.530	.189
MAINTENANCE LABOR AT 1.5% OF TPI	2.592	.926
SUPERVISION 15% OF LABOR COST	.468	.167
OVERHEAD 60% OF TOTAL LABOR COST	2.154	.769
MATERIALS		
OPERATING, 30% OF OPERATING LABOR	.159	.057
MAINTENANCE 1.5% OF TPI	2.592	.926
FUEL	.290	.104
REAGENTS	.190	.068
MISCELLANEOUS	.280	.100
POWER 130 KWH/TON AT $0.02/KWH	7.280	2.600
WATER 600 GAL/TON H2SO4 AT $0.10/1000 GA	.168	.060
TOTAL DIRECT OPERATING COST	16.703	5.966

ANNUAL DIRECT OPERATING COSTS

LEACHING AND CCD SECTION

80000 TPD

LABOR	$MM/YR	$/TON
OPERATING LABOR	.590	.021
MAINTENANCE LABOR AT 1.5% OF TPI	1.211	.043
SUPERVISION 15% OF LABOR COST	.270	.010
OVERHEAD 60% OF TOTAL LABOR COST	1.243	.044
MATERIALS		
OPERATING, 30% OF OPERATING LABOR	.177	.006
MAINTENANCE 1.5% OF TPI	1.211	.043
SULFURIC ACID 200LB/TON AT NO COST	.000	.000
FLOCCULANT - 0.2 LB/TON	5.600	.200
POWER 6390 KW	1.074	.038
WATER 240 GAL/TON AT $0.10/1000	.672	.024
TOTAL DIRECT OPERATING COST	12.049	.430

ANNUAL DIRECT OPERATING COSTS

SOLVENT EXTRACTION AND PRODUCT SECTION

80000 TPD

	$MM/YR	$/TON
LABOR		
OPERATING LABOR	.674	.024
MAINTENANCE LABOR AT 1.5% OF TPI	.790	.028
SUPERVISION 15% OF LABOR COST	.220	.008
OVERHEAD 60% OF TOTAL LABOR COST	1.010	.036
MATERIALS		
OPERATING, 30% OF OPERATING LABOR	.202	.007
MAINTENANCE 1.5% OF TPI	.790	.028
SOLVENT LOSSES	.610	.022
REAGENTS	.506	.018
POWER	.500	.018
TOTAL DIRECT OPERATING COST	5.303	.189

ANNUAL DIRECT OPERATING COSTS

AUXILLARY FACILLITIES

80000 TPD

	$MM/YR	$/TON
LABOR		
OPERATING LABOR	.246	.009
MAINTENANCE LABOR AT 1.5% OF TPI	1.507	.054
SUPERVISION 15% OF LABOR COST	.263	.009
OVERHEAD 60% OF TOTAL LABOR COST	1.209	.043
MATERIALS		
OPERATING, 30% OF OPERATING LABOR	.074	.003
MAINTENANCE 1.5% OF TPI	1.507	.054
TOTAL DIRECT OPERATING COST	4.805	.172

ANNUAL DIRECT OPERATING COSTS

EXPANDED POWER GENERATION SECTION

162 MWH

LABOR	$MM/YR	$/MWH
OPERATING LABOR	.168	.006
MAINTENANCE LABOR AT 1.5% OF TPI	.630	.023
SUPERVISION 15% OF LABOR COST	.120	.004
OVERHEAD 60% OF TOTAL LABOR COST	.551	.020
MATERIALS		
OPERATING, 30% OF OPERATING LABOR	.050	.002
MAINTENANCE 1.5% OF TPI	.630	.023
TOTAL DIRECT OPERATING COST	2.149	1.579

ANNUAL DIRECT OPERATING COSTS

TAILINGS DISPOSAL

80000 TPD

LABOR	$MM/YR	$/TON
OPERATING LABOR	.309	.011
MAINTENANCE LABOR AT 1.5% OF TPI	.940	.034
SUPERVISION 15% OF LABOR COST	.187	.007
OVERHEAD 60% OF TOTAL LABOR COST	.862	.031
MATERIALS		
OPERATING, 30% OF OPERATING LABOR	.093	.003
MAINTENANCE 1.5% OF TPI	.940	.034
LIMESTONE - 2,800,000 T/YR AT $5/TON	14.000	.500
GRINDING BALLS 2 LB/T AT $0.18/LB	1.008	.036
MILL LINERS 0.2 LB/T AT $0.40/LB	.224	.008
POWER	1.510	.054
WATER	.149	.005
TOTAL DIRECT OPERATING COST	20.221	.722

CHATTANOOGA SHALE PROJECT
DEPARTMENT OF ENERGY
MSE JOB 557

CASE 3-1 - 55 PPM URANIUM, 60 PERCENT RECOVERY, ROI 20 PERCENT
URANIUM PRODUCTION ONLY

PRODUCT SALES SUMMARY

		$MM/YR
URANIUM	2310000 LB/YR @271.18 $/LB	626.4
TOTAL SALES REVENUE		626.4

YEAR	-1	-2	-3	1	2	10	20	TOTAL
TOTAL SALES	0	0	0	626	626	626	626	12529
TOTAL OPERATING COST	0	0	0	375	375	375	375	7498
GROSS PROFIT	0	0	0	252	252	252	252	5030
LESS DEPRECIATION	0	0	0	96	67	70	20	1011
NET BEFORE DEPLETION	0	0	0	156	185	182	232	4019
LESS DEPLETION	0	0	0	78	92	91	116	2009
TAXABLE INCOME	0	0	0	78	92	91	116	2009
INVESTMENT TAX CRED.	0	0	0	19	22	1	0	84
INCOME TAX	0	0	0	48	57	53	67	1174
NET INCOME	0	0	0	49	58	39	49	919
PLUS DEPRECIATION	0	0	0	96	67	70	20	1011
PLUS DEPLETION	0	0	0	78	92	91	116	2009
GROSS CASH FLOW	0	0	0	222	217	200	185	3940
WORKING CAPITAL	0	0	94	0	0	0	¯94	0
CAPITAL INVESTMENT	101	219	260	105	23	16	3	1052
NET CASH FLOW	¯101	¯219	¯354	118	194	184	275	2889
CUM. NET CASH FLOW	¯101	¯320	¯674	¯556	¯363	1088	2889	

RETURN ON INVESTMENT 20.00 %

PAYOUT PERIOD 3.88 YEARS

CHATTANOOGA SHALE PROJECT
DEPARTMENT OF ENERGY
MSE JOB 557

CASE 3-2 - 85 PPM URANIUM, 60 PERCENT RECOVERY, ROI 20 PERCENT
URANIUM PRODUCTION ONLY

PRODUCT SALES SUMMARY

		$MM/YR
URANIUM	3570000 LB/YR @175.47 $/LB	626.4
TOTAL SALES REVENUE		626.4

YEAR	-1	-2	-3	1	2	10	20	TOTAL
TOTAL SALES	0	0	0	626	626	626	626	12529
TOTAL OPERATING COST	0	0	0	375	375	375	375	7498
GROSS PROFIT	0	0	0	252	252	252	252	5030
LESS DEPRECIATION	0	0	0	96	67	70	20	1011
NET BEFORE DEPLETION	0	0	0	156	185	182	232	4019
LESS DEPLETION	0	0	0	78	92	91	116	2009
TAXABLE INCOME	0	0	0	78	92	91	116	2009
INVESTMENT TAX CRED.	0	0	0	19	22	1	0	84
INCOME TAX	0	0	0	48	57	53	67	1174
NET INCOME	0	0	0	49	58	39	49	919
PLUS DEPRECIATION	0	0	0	96	67	70	20	1011
PLUS DEPLETION	0	0	0	78	92	91	116	2009
GROSS CASH FLOW	0	0	0	222	217	200	185	3940
WORKING CAPITAL	0	0	94	0	0	0	¯94	0
CAPITAL INVESTMENT	101	219	260	105	23	16	3	1052
NET CASH FLOW	¯101	¯219	¯354	118	194	184	275	2889
CUM. NET CASH FLOW	¯101	¯320	¯674	¯556	¯363	1088	2889	

RETURN ON INVESTMENT 20.00 %

PAYOUT PERIOD 3.88 YEARS

CHATTANOOGA SHALE PROJECT
DEPARTMENT OF ENERGY
MSE JOB 557

CASE 3-3 - 55 PPM URANIUM, 60 PERCENT RECOVERY, ROI 15 PERCENT
URANIUM PRODUCTION ONLY

PRODUCT SALES SUMMARY

		$MM/YR
URANIUM	2310000 LB/YR @242.46 $/LB	560.1
TOTAL SALES REVENUE		560.1

YEAR	-1	-2	-3	1	2	10	20	TOTAL
TOTAL SALES	0	0	0	560	560	560	560	11202
TOTAL OPERATING COST	0	0	0	375	375	375	375	7498
GROSS PROFIT	0	0	0	185	185	185	185	3703
LESS DEPRECIATION	0	0	0	96	67	70	20	1011
NET BEFORE DEPLETION	0	0	0	89	118	115	166	2692
LESS DEPLETION	0	0	0	45	59	58	83	1346
TAXABLE INCOME	0	0	0	45	59	58	83	1346
INVESTMENT TAX CRED.	0	0	0	11	14	1	0	84
INCOME TAX	0	0	0	27	36	34	48	791
NET INCOME	0	0	0	28	37	25	35	639
PLUS DEPRECIATION	0	0	0	96	67	70	20	1011
PLUS DEPLETION	0	0	0	45	59	58	83	1346
GROSS CASH FLOW	0	0	0	168	163	153	138	2997
WORKING CAPITAL	0	0	94	0	0	0	¯94	0
CAPITAL INVESTMENT	101	219	260	105	23	16	3	1052
NET CASH FLOW	¯101	¯219	¯354	64	140	137	228	1945
CUM. NET CASH FLOW	¯101	¯320	¯674	¯610	¯470	617	1945	

RETURN ON INVESTMENT 15.00 %

PAYOUT PERIOD 5.30 YEARS

CHATTANOOGA SHALE PROJECT
DEPARTMENT OF ENERGY
MSE JOB 557

CASE 3-4 - 85 PPM URANIUM, 60 PERCENT RECOVERY, ROI 15 PERCENT
URANIUM PRODUCTION ONLY

PRODUCT SALES SUMMARY

		$MM/YR
URANIUM	3570000 LB/YR @156.89 $/LB	560.1
TOTAL SALES REVENUE		560.1

YEAR	-1	-2	-3	1	2	10	20	TOTAL
TOTAL SALES	0	0	0	560	560	560	560	11202
TOTAL OPERATING COST	0	0	0	375	375	375	375	7498
GROSS PROFIT	0	0	0	185	185	185	185	3703
LESS DEPRECIATION	0	0	0	96	67	70	20	1011
NET BEFORE DEPLETION	0	0	0	89	118	115	166	2692
LESS DEPLETION	0	0	0	45	59	58	83	1346
TAXABLE INCOME	0	0	0	45	59	58	83	1346
INVESTMENT TAX CRED.	0	0	0	11	14	1	0	84
INCOME TAX	0	0	0	27	36	34	48	791
NET INCOME	0	0	0	28	37	25	35	640
PLUS DEPRECIATION	0	0	0	96	67	70	20	1011
PLUS DEPLETION	0	0	0	45	59	58	83	1346
GROSS CASH FLOW	0	0	0	168	163	153	138	2997
WORKING CAPITAL	0	0	94	0	0	0	¯94	0
CAPITAL INVESTMENT	101	219	260	105	23	16	3	1052
NET CASH FLOW	¯101	¯219	¯354	64	140	137	228	1945
CUM. NET CASH FLOW	¯101	¯320	¯674	¯610	¯470	617	1945	

RETURN ON INVESTMENT 15.00 %

PAYOUT PERIOD 5.30 YEARS

CHATTANOOGA SHALE PROJECT
DEPARTMENT OF ENERGY
MSE JOB 557

CASE 3-5 - 130 PPM URANIUM, 60 PERCENT RECOVERY, ROI 20 PERCENT
URANIUM PRODUCTION ONLY

PRODUCT SALES SUMMARY

		$MM/YR
URANIUM	5460000 LB/YR @114.73 $/LB	626.4
TOTAL SALES REVENUE		626.4

YEAR	-1	-2	-3	1	2	10	20	TOTAL
TOTAL SALES	0	0	0	626	626	626	626	12529
TOTAL OPERATING COST	0	0	0	375	375	375	375	7498
GROSS PROFIT	0	0	0	252	252	252	252	5030
LESS DEPRECIATION	0	0	0	96	67	70	20	1011
NET BEFORE DEPLETION	0	0	0	156	185	182	232	4019
LESS DEPLETION	0	0	0	78	92	91	116	2009
TAXABLE INCOME	0	0	0	78	92	91	116	2009
INVESTMENT TAX CRED.	0	0	0	19	22	1	0	84
INCOME TAX	0	0	0	48	57	53	67	1174
NET INCOME	0	0	0	49	58	39	49	919
PLUS DEPRECIATION	0	0	0	96	67	70	20	1011
PLUS DEPLETION	0	0	0	78	92	91	116	2009
GROSS CASH FLOW	0	0	0	222	217	200	185	3940
WORKING CAPITAL	0	0	94	0	0	0	¯94	0
CAPITAL INVESTMENT	101	219	260	105	23	16	3	1052
NET CASH FLOW	¯101	¯219	¯354	118	194	184	275	2889
CUM. NET CASH FLOW	¯101	¯320	¯674	¯556	¯363	1088	2889	

RETURN ON INVESTMENT 20.00 %

PAYOUT PERIOD 3.88 YEARS

CHATTANOOGA SHALE PROJECT
DEPARTMENT OF ENERGY
MSE JOB 557

CASE 3-6 - 45 PPM URANIUM, 60 PERCENT RECOVERY, ROI 20 PERCENT
URANIUM PRODUCTION ONLY

PRODUCT SALES SUMMARY

		$MM/YR
URANIUM	1890000 LB/YR @331.45 $/LB	626.4
TOTAL SALES REVENUE		626.4

YEAR	-1	-2	-3	1	2	10	20	TOTAL
TOTAL SALES	0	0	0	626	626	626	626	12529
TOTAL OPERATING COST	0	0	0	375	375	375	375	7498
GROSS PROFIT	0	0	0	252	252	252	252	5030
LESS DEPRECIATION	0	0	0	96	67	70	20	1011
NET BEFORE DEPLETION	0	0	0	156	185	182	232	4019
LESS DEPLETION	0	0	0	78	92	91	116	2009
TAXABLE INCOME	0	0	0	78	92	91	116	2009
INVESTMENT TAX CRED.	0	0	0	19	22	1	0	84
INCOME TAX	0	0	0	48	57	53	67	1174
NET INCOME	0	0	0	49	58	39	49	920
PLUS DEPRECIATION	0	0	0	96	67	70	20	1011
PLUS DEPLETION	0	0	0	78	92	91	116	2009
GROSS CASH FLOW	0	0	0	222	217	200	185	3940
WORKING CAPITAL	0	0	94	0	0	0	¯94	0
CAPITAL INVESTMENT	101	219	260	105	23	16	3	1052
NET CASH FLOW	¯101	¯219	¯354	118	194	184	275	2889
CUM. NET CASH FLOW	¯101	¯320	¯674	¯556	¯362	1089	2889	

RETURN ON INVESTMENT 20.00 %

PAYOUT PERIOD 3.88 YEARS

CHATTANOOGA SHALE PROJECT
DEPARTMENT OF ENERGY
MSE JOB 557

CASE 3-7 - 55 PPM URANIUM, 70 PERCENT RECOVERY, ROI 20 PERCENT
URANIUM PRODUCTION ONLY

PRODUCT SALES SUMMARY

		$MM/YR
URANIUM	2695000 LB/YR @232.44 $/LB	626.4
TOTAL SALES REVENUE		626.4

YEAR	-1	-2	-3	1	2	10	20	TOTAL
TOTAL SALES	0	0	0	626	626	626	626	12529
TOTAL OPERATING COST	0	0	0	375	375	375	375	7498
GROSS PROFIT	0	0	0	252	252	252	252	5030
LESS DEPRECIATION	0	0	0	96	67	70	20	1011
NET BEFORE DEPLETION	0	0	0	156	185	182	232	4019
LESS DEPLETION	0	0	0	78	92	91	116	2009
TAXABLE INCOME	0	0	0	78	92	91	116	2009
INVESTMENT TAX CRED.	0	0	0	19	22	1	0	84
INCOME TAX	0	0	0	48	57	53	67	1174
NET INCOME	0	0	0	49	58	39	49	919
PLUS DEPRECIATION	0	0	0	96	67	70	20	1011
PLUS DEPLETION	0	0	0	78	92	91	116	2009
GROSS CASH FLOW	0	0	0	222	217	200	185	3940
WORKING CAPITAL	0	0	94	0	0	0	¯94	0
CAPITAL INVESTMENT	101	219	260	105	23	16	3	1052
NET CASH FLOW	¯101	¯219	¯354	118	194	184	275	2889
CUM. NET CASH FLOW	¯101	¯320	¯674	¯556	¯363	1088	2889	

RETURN ON INVESTMENT 20.00 %

PAYOUT PERIOD 3.88 YEARS

CHATTANOOGA SHALE PROJECT
DEPARTMENT OF ENERGY
MSE JOB 557

CASE 3-8 - 55 PPM URANIUM, 80 PERCENT RECOVERY, ROI 20 PERCENT
URANIUM PRODUCTION ONLY

<u>PRODUCT SALES SUMMARY</u>

		$MM/YR
URANIUM	3080000 LB/YR @203.39 $/LB	626.4
<u>TOTAL SALES REVENUE</u>		626.4

YEAR	-1	-2	-3	1	2	10	20	TOTAL
TOTAL SALES	0	0	0	626	626	626	626	12529
TOTAL OPERATING COST	0	0	0	375	375	375	375	7498
GROSS PROFIT	0	0	0	252	252	252	252	5030
LESS DEPRECIATION	0	0	0	96	67	70	20	1011
NET BEFORE DEPLETION	0	0	0	156	185	182	232	4019
LESS DEPLETION	0	0	0	78	92	91	116	2009
TAXABLE INCOME	0	0	0	78	92	91	116	2009
INVESTMENT TAX CRED.	0	0	0	19	22	1	0	84
INCOME TAX	0	0	0	48	57	53	67	1174
NET INCOME	0	0	0	49	58	39	49	920
PLUS DEPRECIATION	0	0	0	96	67	70	20	1011
PLUS DEPLETION	0	0	0	78	92	91	116	2009
GROSS CASH FLOW	0	0	0	222	217	200	185	3940
WORKING CAPITAL	0	0	94	0	0	0	-94	0
CAPITAL INVESTMENT	101	219	260	105	23	16	3	1052
NET CASH FLOW	-101	-219	-354	118	194	184	275	2889
CUM. NET CASH FLOW	-101	-320	-674	-556	-362	1089	2889	

RETURN ON INVESTMENT 20.00 %

PAYOUT PERIOD 3.88 YEARS

CASH FLOW ANALYSIS INPUT DATA

TOTAL COST SUMMARY

CAPITAL COST SUMMARY	$MM
TOTAL MINE CAPITAL	301.02
BACKFILLING EQUIP.	54.56
TOTAL URANIUM PLANT	322.09
TAILINGS DISPOSAL	62.40
TAILINGS DAM	136.28
CONTINGENCY @ 20%	175.27
TOTAL CAPITAL COST	1051.62

OPERATING COST SUMMARY	$MM/YR
DIRECT OPERATING COSTS	
MINE	168.70
CRUSHING SECTION	4.55
GRINDING SECTION	9.97
LEACHING SECTION	98.56
S-X PROD SECTION	6.15
AUXILLARY FAC.	5.64
TAILINGS DISPOSAL	21.47
TOTAL DIRECT COST	315.03
INDIRECT COSTS	
LOCAL TAXES & INSURANCE 2.7% OF CAPITAL	28.39
GENERAL AND ADMINISTRATION 10% OF DIRECT	31.50
TOTAL INDIRECT COST	59.90
TOTAL OPERATING COST	374.92

CAPITAL OUTLAY SCHEDULE

YEAR	-1	-2	-3	1	2	3-5
MOBILE EQUIPMENT	5.3	5.2	2.9	35.1	2.7	20.4
MISCELLANEOUS	.8	5.6	10.9	18.1	10.0	5.0
MINE DEVELOPMENT	1.0	17.7	15.3	.0	.0	.0
TOTAL MINE CAPITAL	7.1	28.5	29.1	53.2	12.7	25.4
BACKFILLING EQUIP.	.0	.0	27.3	27.3	.0	.0
CRUSHING PLANT	10.6	21.2	21.2	.0	.0	.0
GRINDING PLANT	7.2	14.4	14.4	.0	.0	.0
LEACHING AND CCD	16.1	32.2	32.2	.0	.0	.0
SOL. EXT. AND PROD	10.5	21.0	21.0	.0	.0	.0
AUXILLARY FAC.	20.0	40.0	40.0	.0	.0	.0
TOTAL URANIUM PLANT	64.4	128.8	128.8	.0	.0	.0
TAILINGS DISPOSAL	12.5	25.0	25.0	.0	.0	.0
TAILINGS DAM	.0	.0	6.8	6.8	6.8	20.4
CONTINGENCY @ 20%	16.8	36.5	43.4	17.5	3.9	9.2
TOTAL CAPITAL OUTLAY	100.8	218.8	260.4	104.8	23.4	55.0

YEAR	6-8	9-11	12-14	15-17	18-20	TOTAL
MOBILE EQUIPMENT	17.2	36.0	26.6	32.5	16.4	200.4
MISCELLANEOUS	4.2	4.5	3.4	1.9	2.2	66.6
MINE DEVELOPMENT	.0	.0	.0	.0	.0	34.0
TOTAL MINE CAPITAL	21.4	40.5	30.0	34.5	18.6	301.0
BACKFILLING EQUIP.	.0	.0	.0	.0	.0	54.6
CRUSHING PLANT	.0	.0	.0	.0	.0	53.0
GRINDING PLANT	.0	.0	.0	.0	.0	36.1
LEACHING AND CCD	.0	.0	.0	.0	.0	80.5
SOL. EXT. AND PROD	.0	.0	.0	.0	.0	52.5
AUXILLARY FAC.	.0	.0	.0	.0	.0	100.1
TOTAL URANIUM PLANT	.0	.0	.0	.0	.0	322.1
TAILINGS DISPOSAL	.0	.0	.0	.0	.0	62.4
TAILINGS DAM	20.4	20.4	20.4	20.4	13.6	136.3
CONTINGENCY @ 20%	8.4	12.2	10.1	11.0	6.4	175.3
TOTAL CAPITAL OUTLAY	50.2	73.2	60.5	65.9	38.6	1051.6

ANNUAL DIRECT OPERATING COSTS

MINING

100000 TPD

OPERATING COST	$MM/YR	$/TON
MINING COSTS AT $2.336/TON	81.760	2.336
BACKFILLING COSTS AT $0.484/TON	16.940	.484
LAND AND ROYALTY	70.000	2.000
TOTAL DIRECT OPERATING COST	168.700	4.820

ANNUAL DIRECT OPERATING COSTS

CRUSHING SECTION

100000 TPD

UNIT COST	$MM/YR	$/TON
CRUSHING COSTS AT $0.13 PER TON	4.550	.130
TOTAL DIRECT OPERATING COST	4.550	.130

ANNUAL DIRECT OPERATING COSTS

GRINDING SECTION

100000 TPD

LABOR	$MM/YR	$/TON
OPERATING LABOR	.590	.017
MAINTENANCE LABOR AT 1.5% OF TPI	.650	.019
SUPERVISION 15% OF LABOR COST	.186	.005
OVERHEAD 60% OF TOTAL LABOR COST	.855	.024
MATERIALS		
OPERATING, 30% OF OPERATING LABOR	.177	.005
MAINTENANCE 1.5% OF TPI	.650	.019
GRINDING BALLS 0.2 LBS/TON AT $.18/LB	1.260	.036
GRINDING LINERS 0.02 LBS/TON AT $.40/LB	.280	.008
POWER 7.6 KWH/TON AT $0.02/KWH	5.320	.152
TOTAL DIRECT OPERATING COST	9.968	.285

ANNUAL DIRECT OPERATING COSTS

LEACHING AND CCD SECTION

100000 TPD

	$MM/YR	$/TON
LABOR		
OPERATING LABOR	.590	.017
MAINTENANCE LABOR AT 1.5% OF TPI	1.448	.041
SUPERVISION 15% OF LABOR COST	.306	.009
OVERHEAD 60% OF TOTAL LABOR COST	1.406	.040
MATERIALS		
OPERATING, 30% OF OPERATING LABOR	.177	.005
MAINTENANCE 1.5% OF TPI	1.448	.041
SULFURIC ACID 200 LB/TON AT $30/TON	84.000	2.400
FLOCCULANT - 0.2 LB/TON	7.000	.200
POWER 6390 KW	1.343	.038
WATER 240 GAL/TON AT $0.10/1000	.840	.024
TOTAL DIRECT OPERATING COST	98.558	2.816

ANNUAL DIRECT OPERATING COSTS

SOLVENT EXTRACTION AND PRODUCT SECTION

100000 TPD

	$MM/YR	$/TON
LABOR		
OPERATING LABOR	.674	.019
MAINTENANCE LABOR AT 1.5% OF TPI	.945	.027
SUPERVISION 15% OF LABOR COST	.243	.007
OVERHEAD 60% OF TOTAL LABOR COST	1.117	.032
MATERIALS		
OPERATING, 30% OF OPERATING LABOR	.202	.006
MAINTENANCE 1.5% OF TPI	.945	.027
SOLVENT LOSSES	.762	.022
REAGENTS	.633	.018
POWER	.625	.018
TOTAL DIRECT OPERATING COST	6.145	.176

ANNUAL DIRECT OPERATING COSTS

AUXILLARY FACILLITIES

100000 TPD

	$MM/YR	$/TON
LABOR		
OPERATING LABOR	.246	.007
MAINTENANCE LABOR AT 1.5% OF TPI	1.801	.051
SUPERVISION 15% OF LABOR COST	.307	.009
OVERHEAD 60% OF TOTAL LABOR COST	1.412	.040
MATERIALS		
OPERATING, 30% OF OPERATING LABOR	.074	.002
MAINTENANCE 1.5% OF TPI	1.801	.051
TOTAL DIRECT OPERATING COST	5.641	.161

ANNUAL DIRECT OPERATING COSTS

TAILINGS DISPOSAL

100000 TPD

	$MM/YR	$/TON
LABOR		
OPERATING LABOR	.309	.009
MAINTENANCE LABOR AT 1.5% OF TPI	1.123	.032
SUPERVISION 15% OF LABOR COST	.215	.006
OVERHEAD 60% OF TOTAL LABOR COST	.988	.028
MATERIALS		
OPERATING, 30% OF OPERATING LABOR	.093	.003
MAINTENANCE 1.5% OF TPI	1.123	.032
LIMESTONE - 2,800,000 T/YR AT $5/TON	14.000	.400
GRINDING BALLS 2 LB/T AT $0.18/LB	1.260	.036
MILL LINERS 0.2 LB/T AT $0.40/LB	.280	.008
POWER	1.887	.054
WATER	.186	.005
TOTAL DIRECT OPERATING COST	21.465	.613

CHATTANOOGA SHALE PROJECT
DEPARTMENT OF ENERGY
MSE JOB 557

CASE 4-1 - 55 PPM URANIUM, 60 PERCENT RECOVERY, ROI 15 PERCENT
NO SYNCRUDE, SULFUR, AMMONIA, OR POWER
BYPRODUCT METAL CREDITS INCLUDED

PRODUCT SALES SUMMARY

				$MM/YR
URANIUM	2310000 LB/YR	@170.59	$/LB	394.1
VANADIUM	21280000 LB/YR	@ 4.91	$/LB	104.5
COBALT	8050000 LB/YR	@ 8.54	$/LB	68.8
NICKEL	18550000 LB/YR	@ 2.13	$/LB	39.5
MOLYBDENUM	7000000 LB/YR	@ 4.50	$/LB	31.5
THORIUM	350000 LB/YR	@ 2.00	$/LB	.7
TOTAL SALES REVENUE				639.1

YEAR	-1	-2	-3	1	2	10	20	TOTAL
TOTAL SALES	0	0	0	639	639	639	639	12781
TOTAL OPERATING COST	0	0	0	404	404	404	404	8079
GROSS PROFIT	0	0	0	235	235	235	235	4702
LESS DEPRECIATION	0	0	0	113	84	87	20	1222
NET BEFORE DEPLETION	0	0	0	122	151	148	216	3480
LESS DEPLETION	0	0	0	61	75	74	108	1740
TAXABLE INCOME	0	0	0	61	75	74	108	1740
INVESTMENT TAX CRED.	0	0	0	15	18	1	0	101
INCOME TAX	0	0	0	37	46	43	62	1021
NET INCOME	0	0	0	38	47	32	46	820
PLUS DEPRECIATION	0	0	0	113	84	87	20	1222
PLUS DEPLETION	0	0	0	61	75	74	108	1740
GROSS CASH FLOW	0	0	0	212	207	193	173	3782
WORKING CAPITAL	0	0	101	0	0	0	-101	0
CAPITAL INVESTMENT	143	303	345	105	23	16	3	1262
NET CASH FLOW	-143	-303	-446	108	184	178	271	2520
CUM. NET CASH FLOW	-143	-446	-892	-784	-601	819	2520	

RETURN ON INVESTMENT 15.00 %

PAYOUT PERIOD 5.23 YEARS

CHATTANOOGA SHALE PROJECT
DEPARTMENT OF ENERGY
MSE JOB 557

CASE 4-2 - 55 PPM URANIUM, 60 PERCENT RECOVERY, ROI 20 PERCENT
NO SYNCRUDE, SULFUR, AMMONIA, OR POWER
BYPRODUCT METAL CREDITS INCLUDED

<u>PRODUCT SALES SUMMARY</u>

				$MM/YR
URANIUM	2310000 LB/YR	@208.44 $/LB		481.5
VANADIUM	21280000 LB/YR	@ 4.91 $/LB		104.5
COBALT	8050000 LB/YR	@ 8.54 $/LB		68.8
NICKEL	18550000 LB/YR	@ 2.13 $/LB		39.5
MOLYBDENUM	7000000 LB/YR	@ 4.50 $/LB		31.5
THORIUM	350000 LB/YR	@ 2.00 $/LB		.7

<u>TOTAL SALES REVENUE</u> 726.5

YEAR	-1	-2	-3	1	2	10	20	TOTAL
TOTAL SALES	0	0	0	726	726	726	726	14530
TOTAL OPERATING COST	0	0	0	404	404	404	404	8079
GROSS PROFIT	0	0	0	323	323	323	323	6451
LESS DEPRECIATION	0	0	0	113	84	87	20	1222
NET BEFORE DEPLETION	0	0	0	209	238	235	303	5229
LESS DEPLETION	0	0	0	105	119	118	151	2614
TAXABLE INCOME	0	0	0	105	119	118	151	2614
INVESTMENT TAX CRED.	0	0	0	25	29	1	0	101
INCOME TAX	0	0	0	64	73	68	88	1526
NET INCOME	0	0	0	65	75	51	64	1189
PLUS DEPRECIATION	0	0	0	113	84	87	20	1222
PLUS DEPLETION	0	0	0	105	119	118	151	2614
GROSS CASH FLOW	0	0	0	283	278	256	235	5026
WORKING CAPITAL	0	0	101	0	0	0	¯101	0
CAPITAL INVESTMENT	143	303	345	105	23	16	3	1262
NET CASH FLOW	¯143	¯303	¯446	179	255	240	333	3763
CUM. NET CASH FLOW	¯143	¯446	¯892	¯713	¯458	1441	3763	

RETURN ON INVESTMENT 20.00 %

PAYOUT PERIOD 3.83 YEARS

CASH FLOW ANALYSIS INPUT DATA

TOTAL COST SUMMARY

CAPITAL COST SUMMARY	$MM
TOTAL MINE CAPITAL	301.02
BACKFILLING EQUIP.	54.56
TOTAL URANIUM PLANT	322.09
BY-PRODUCT PLANT	175.60
TAILINGS DISPOSAL	62.40
TAILINGS DAM	136.28
CONTINGENCY @ 20%	210.39
TOTAL CAPITAL COST	1262.34

OPERATING COST SUMMARY	$MM/YR
DIRECT OPERATING COSTS	
MINING, LAND, ROYALTY	168.70
CRUSHING SECTION	4.55
GRINDING SECTION	9.97
LEACHING SECTION	98.56
S-X PROD SECTION	6.15
AUXILLARY FAC.	5.64
TAILINGS DISPOSAL	21.46
BY-PRODUCT SECTION	21.21
TOTAL DIRECT COST	336.24
INDIRECT COSTS	
LOCAL TAXES & INSURANCE 2.7% OF CAPITAL	34.08
GENERAL AND ADMINISTRATION 10% OF DIRECT	33.62
TOTAL INDIRECT COST	67.71
TOTAL OPERATING COST	403.94

CAPITAL OUTLAY SCHEDULE

YEAR	-1	-2	-3	1	2	3-5
MOBILE EQUIPMENT	5.3	5.2	2.9	35.1	2.7	20.4
MISCELLANEOUS	.8	5.6	10.9	18.1	10.0	5.0
MINE DEVELOPMENT	1.0	17.7	15.3	.0	.0	.0
TOTAL MINE CAPITAL	7.1	28.5	29.1	53.2	12.7	25.4
BACKFILLING EQUIP.	.0	.0	27.3	27.3	.0	.0
CRUSHING PLANT	10.6	21.2	21.2	.0	.0	.0
GRINDING PLANT	7.2	14.4	14.4	.0	.0	.0
LEACHING AND CCD	16.1	32.2	32.2	.0	.0	.0
SOL. EXT. AND PROD	10.5	21.0	21.0	.0	.0	.0
AUXILLARY FAC.	20.0	40.0	40.0	.0	.0	.0
TOTAL URANIUM PLANT	64.4	128.8	128.8	.0	.0	.0
BY-PRODUCT PLANT	35.1	70.2	70.2	.0	.0	.0
TAILINGS DISPOSAL	12.5	25.0	25.0	.0	.0	.0
TAILINGS DAM	.0	.0	6.8	6.8	6.8	20.4
CONTINGENCY @ 20%	23.8	50.5	57.4	17.5	3.9	9.2
TOTAL CAPITAL OUTLAY	142.9	303.1	344.7	104.8	23.4	55.0

YEAR	6-8	9-11	12-14	15-17	18-20	TOTAL
MOBILE EQUIPMENT	17.2	36.0	26.6	32.5	16.4	200.4
MISCELLANEOUS	4.2	4.5	3.4	1.9	2.2	66.6
MINE DEVELOPMENT	.0	.0	.0	.0	.0	34.0
TOTAL MINE CAPITAL	21.4	40.5	30.0	34.5	18.6	301.0
BACKFILLING EQUIP.	.0	.0	.0	.0	.0	54.6
CRUSHING PLANT	.0	.0	.0	.0	.0	53.0
GRINDING PLANT	.0	.0	.0	.0	.0	36.1
LEACHING AND CCD	.0	.0	.0	.0	.0	80.5
SOL. EXT. AND PROD	.0	.0	.0	.0	.0	52.5
AUXILLARY FAC.	.0	.0	.0	.0	.0	100.1
TOTAL URANIUM PLANT	.0	.0	.0	.0	.0	322.1
BY-PRODUCT PLANT	.0	.0	.0	.0	.0	175.6
TAILINGS DISPOSAL	.0	.0	.0	.0	.0	62.4
TAILINGS DAM	20.4	20.4	20.4	20.4	13.6	136.3
CONTINGENCY @ 20%	8.4	12.2	10.1	11.0	6.4	210.4
TOTAL CAPITAL OUTLAY	50.2	73.2	60.5	65.9	38.6	1262.3

ANNUAL DIRECT OPERATING COSTS

MINING

100000 TPD

OPERATING COST	$MM/YR	$/TON
MINING COSTS AT $2.336/TON	81.760	2.336
BACKFILLING COSTS AT $0.484/TON	16.940	.484
LAND AND ROYALTY	70.000	2.000
TOTAL DIRECT OPERATING COST	168.700	4.820

ANNUAL DIRECT OPERATING COSTS

CRUSHING SECTION

100000 TPD

UNIT COST	$MM/YR	$/TON
CRUSHING COSTS AT $0.13 PER TON	4.550	.130
TOTAL DIRECT OPERATING COST	4.550	.130

ANNUAL DIRECT OPERATING COSTS

GRINDING SECTION

80000 TPD

	$MM/YR	$/TON
LABOR		
OPERATING LABOR	.590	.021
MAINTENANCE LABOR AT 1.5% OF TPI	.650	.023
SUPERVISION 15% OF LABOR COST	.186	.007
OVERHEAD 60% OF TOTAL LABOR COST	.855	.031
MATERIALS		
OPERATING, 30% OF OPERATING LABOR	.177	.006
MAINTENANCE 1.5% OF TPI	.650	.023
GRINDING BALLS 0.2 LBS/TON AT $.18/LB	1.260	.045
GRINDING LINERS 0.02 LBS/TON AT $.40/LB	.280	.010
POWER 7.6 KWH/TON AT $0.02/KWH	5.320	.190
TOTAL DIRECT OPERATING COST	9.968	.356

ANNUAL DIRECT OPERATING COSTS

LEACHING AND CCD SECTION

80000 TPD

	$MM/YR	$/TON
LABOR		
OPERATING LABOR	.590	.021
MAINTENANCE LABOR AT 1.5% OF TPI	1.448	.052
SUPERVISION 15% OF LABOR COST	.306	.011
OVERHEAD 60% OF TOTAL LABOR COST	1.406	.050
MATERIALS		
OPERATING, 30% OF OPERATING LABOR	.177	.006
MAINTENANCE 1.5% OF TPI	1.448	.052
SULFURIC ACID 200LB/TON AT NO COST	84.000	3.000
FLOCCULANT - 0.2 LB/TON	7.000	.250
POWER 6390 KW	1.343	.048
WATER 240 GAL/TON AT $0.10/1000	.840	.030
TOTAL DIRECT OPERATING COST	98.558	3.520

ANNUAL DIRECT OPERATING COSTS

SOLVENT EXTRACTION AND PRODUCT SECTION

80000 TPD

LABOR	$MM/YR	$/TON
OPERATING LABOR	.674	.024
MAINTENANCE LABOR AT 1.5% OF TPI	.945	.034
SUPERVISION 15% OF LABOR COST	.243	.009
OVERHEAD 60% OF TOTAL LABOR COST	1.117	.040
MATERIALS		
OPERATING, 30% OF OPERATING LABOR	.202	.007
MAINTENANCE 1.5% OF TPI	.945	.034
SOLVENT LOSSES	.762	.027
REAGENTS	.633	.023
POWER	.625	.022
TOTAL DIRECT OPERATING COST	6.145	.219

ANNUAL DIRECT OPERATING COSTS

AUXILLARY FACILLITIES

80000 TPD

LABOR	$MM/YR	$/TON
OPERATING LABOR	.246	.009
MAINTENANCE LABOR AT 1.5% OF TPI	1.801	.064
SUPERVISION 15% OF LABOR COST	.307	.011
OVERHEAD 60% OF TOTAL LABOR COST	1.412	.050
MATERIALS		
OPERATING, 30% OF OPERATING LABOR	.074	.003
MAINTENANCE 1.5% OF TPI	1.801	.064
TOTAL DIRECT OPERATING COST	5.641	.201

ANNUAL DIRECT OPERATING COSTS

TAILINGS DISPOSAL

80000 TPD

	$MM/YR	$/TON
LABOR		
OPERATING LABOR	.309	.011
MAINTENANCE LABOR AT 1.5% OF TPI	1.123	.040
SUPERVISION 15% OF LABOR COST	.215	.008
OVERHEAD 60% OF TOTAL LABOR COST	.988	.035
MATERIALS		
OPERATING, 30% OF OPERATING LABOR	.093	.003
MAINTENANCE 1.5% OF TPI	1.123	.040
LIMESTONE - 2,800,000 T/YR AT $5/TON	14.000	.500
GRINDING BALLS 2 LB/T AT $0.18/LB	1.260	.045
MILL LINERS 0.2 LB/T AT $0.40/LB	.280	.010
POWER	1.887	.067
WATER	.186	.007
TOTAL DIRECT OPERATING COST	21.464	.767

ANNUAL DIRECT OPERATING COSTS

BY PRODUCT PLANT

80000 TPD

	$MM/YR	$/TON
LABOR		
OPERATING LABOR	2.696	.096
MAINTENANCE LABOR AT 1.5% OF TPI	3.161	.113
SUPERVISION 15% OF LABOR COST	.879	.031
OVERHEAD 60% OF TOTAL LABOR COST	4.041	.144
MATERIALS		
OPERATING, 30% OF OPERATING LABOR	.809	.029
MAINTENANCE 1.5% OF TPI	3.161	.113
SOLVENT LOSSES	2.440	.087
REAGENTS	2.024	.072
POWER	2.000	.071
TOTAL DIRECT OPERATING COST	21.210	.758

DISCUSSION OF ECONOMIC EVALUATION

Detailed data sheets for each of the sub-cases are included in pages V-11 through V-64. The data comprise computer print-outs covering a product sales summary, and a financial analysis for years -1, -2, -3, 1, 2, 10, and 20. The return on investment and payout period for each subcase is given.

A review of the economic evaluation data indicates the capital and operating costs summarized in the following table:

Case	$MM Capital Cost	Annual Operating Cost
Making uranium, syncrude, by-product metals	2,303	416
Making uranium, syncrude	2,092	387
Making uranium only	1,052	375
Making uranium and by-product metals	1,262	404

In Case 1, in which uranium, syncrude, and by-product metals are made, Figure V-1 graphically shows the return on investmnt versus the price of uranium for assumed 60 percent U recovery, 55 ppm U shale, and prices of $14 per barrel of syncrude, and for $20 per barrel. For $14 syncrude, the return varies from 8.9 percent R.O.I. at a price of $50.12 per pound of uranium to 20 percent R.O.I. at a price of $221.23 per pound of U. If $20 syncrude is assumed, the return is 12.80 percent R.O.I. at $50.12 U price and 20 percent R.O.I. at $172.44 per pound of U. In Subcase 1, at 55 ppm U and current U and syncrude prices, making by-product metals, uranium provides only $115.8 million of the total annual sales income of $708.4 million, or 16.3 percent of the total income. The market impact of the by-product metal production is a critical factor in Case 1, and a careful market survey is warranted.

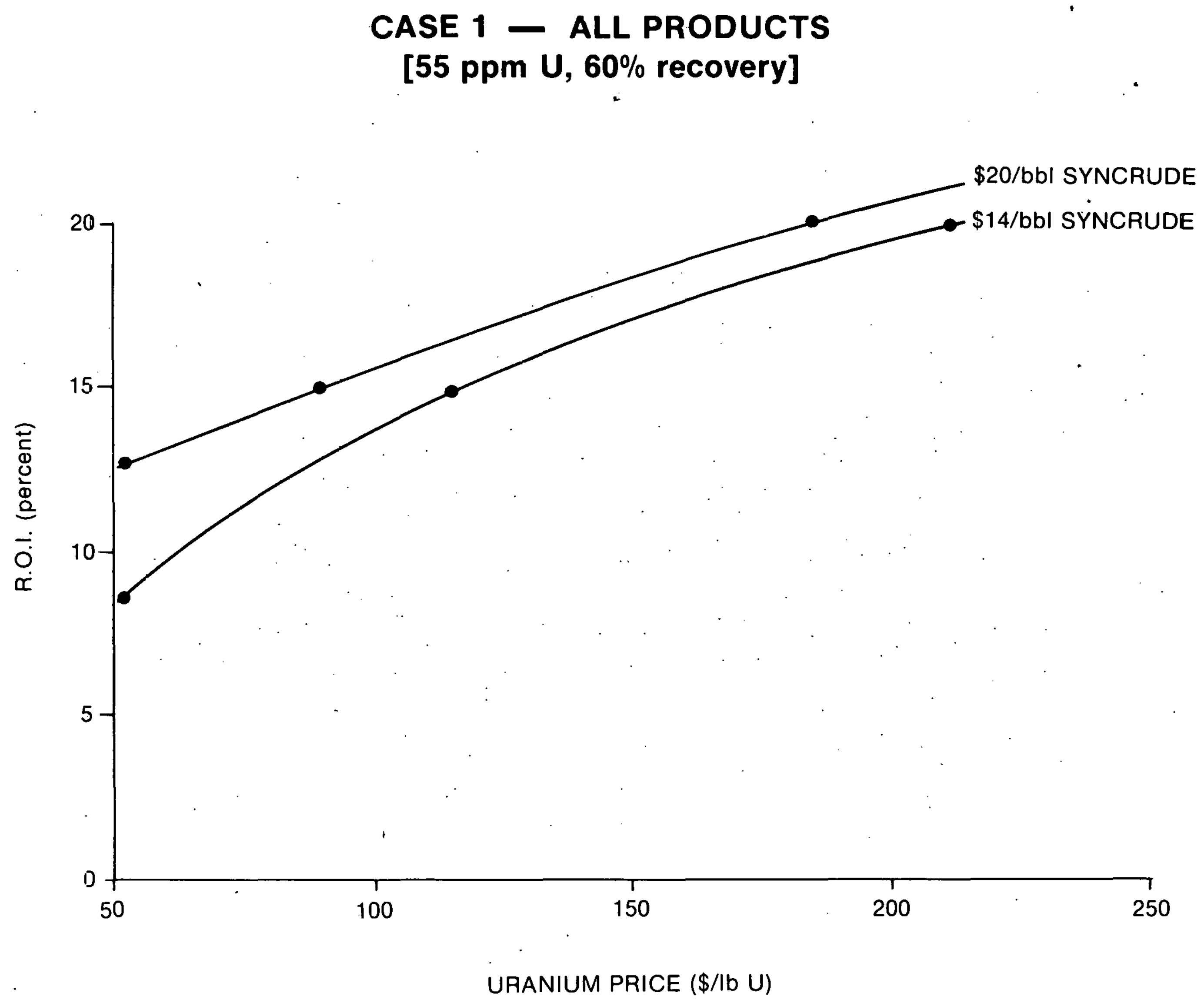

CASE 1 — ALL PRODUCTS
[55 ppm U, 60% recovery]
$20/bbl SYNCRUDE
$14/bbl SYNCRUDE
R.O.I. (percent)
0
5
10
15
20
50
100
150
200
250
URANIUM PRICE ($/lb U)

FIGURE V-1

Data for Case 2, making uranium, syncrude, ammonia, sulfur, and power, but no by-product metals, are presented in Figure V-2, plotting return on investment versus uranium price. For assumed $14 per barrel syncrude price, a slight loss is incurred at $50.12 U and a 20 percent R.O.I. at $283.02 U price. At $20 syncrude, 5.6 percent R.O.I. is made at $50.12 U price, and 20 percent R.O.I. at $234.23 U price.

Case 3 data are based upon making uranium only. In Figure V-3, the uranium price is plotted against percent recovery of the uranium from shale. For 60 percent recovery, a price of $271.18 is required for a 20 percent R.O.I., whereas for 80 percent recovery the required price drops to $203.39. If uranium grade is plotted versus uranium price, as in Figure V-4, at 45 ppm U a price of $331.45 is needed for 20 percent R.O.I., and a price of $114.73 at 130 ppm U.

Case 4 covers the making of uranium and by-product metals without syncrude, sulfur, ammonia, and power. Data are not graphed. For a 15 percent R.O.I., a price of $170.59 is required for uranium, and for 20 percent R.O.I., a price of $208.44.

The price of uranium can be slightly cheaper when syncrude is not made, but all hydrocarbons, ammonia, sulfur, and heat would be wasted as compared to Cases 2-3 and 3-1.

CASE 2 — URANIUM, SYNCRUDE, S, NH3, POWER, NO METAL BYPRODUCTS [55 ppm U, 60% recovery]

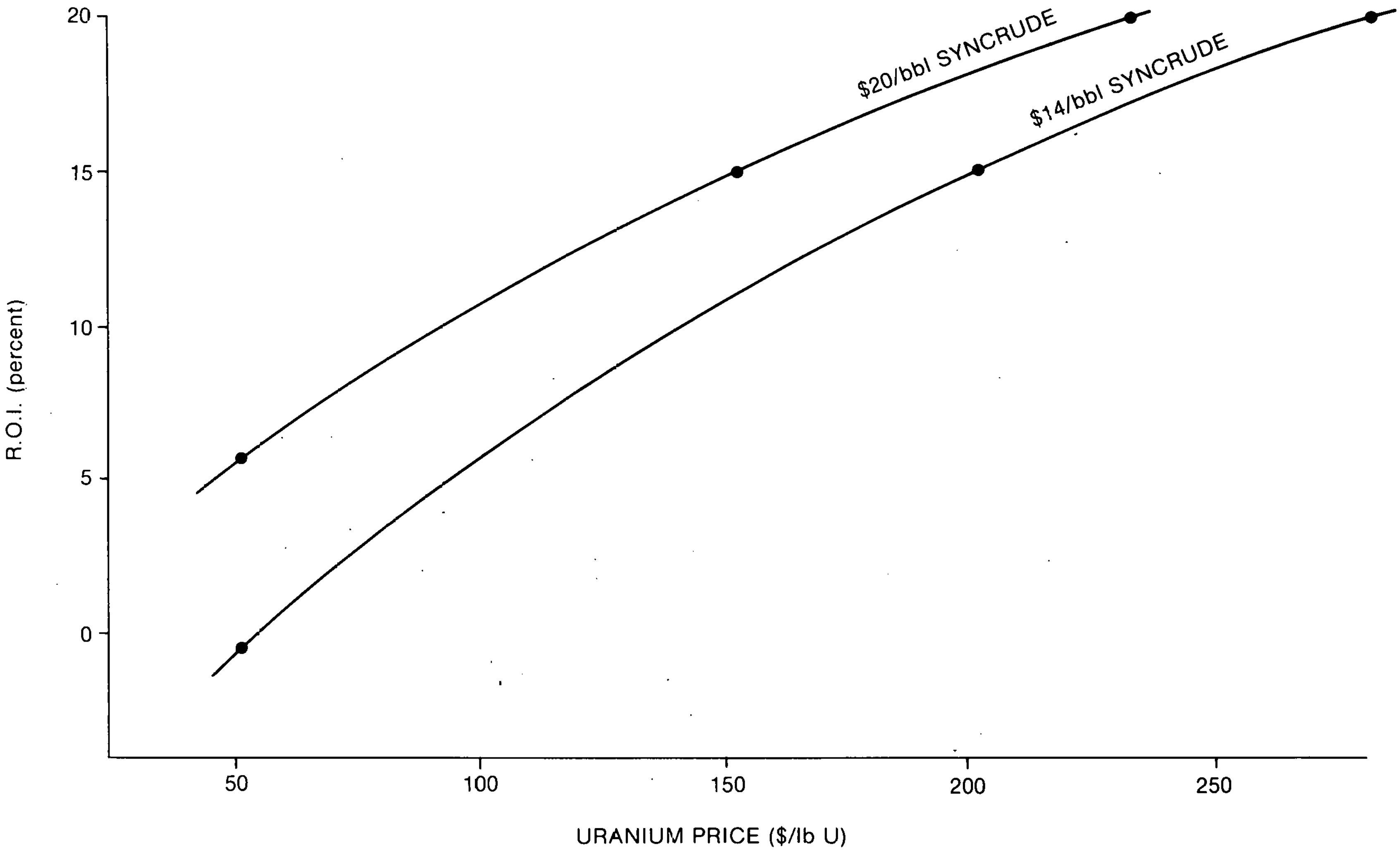


FIGURE V-2

CASE 3 — URANIUM ONLY (price vs percent recovery)
[55 ppm U, 20% R.O.I.]

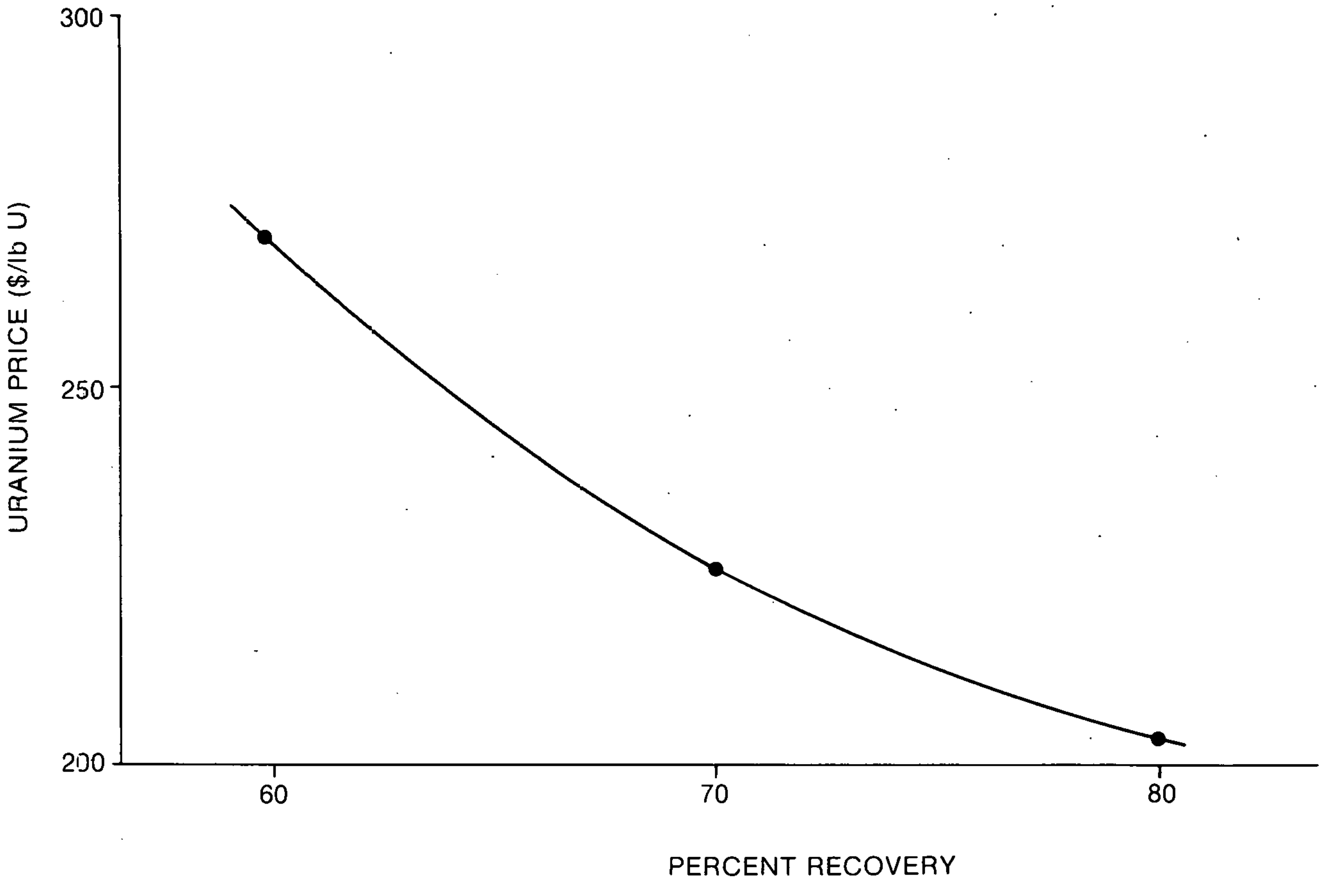


FIGURE V-3

CASE 3 — URANIUM ONLY (price vs grade)
[60% recovery, 20% R.O.I.]

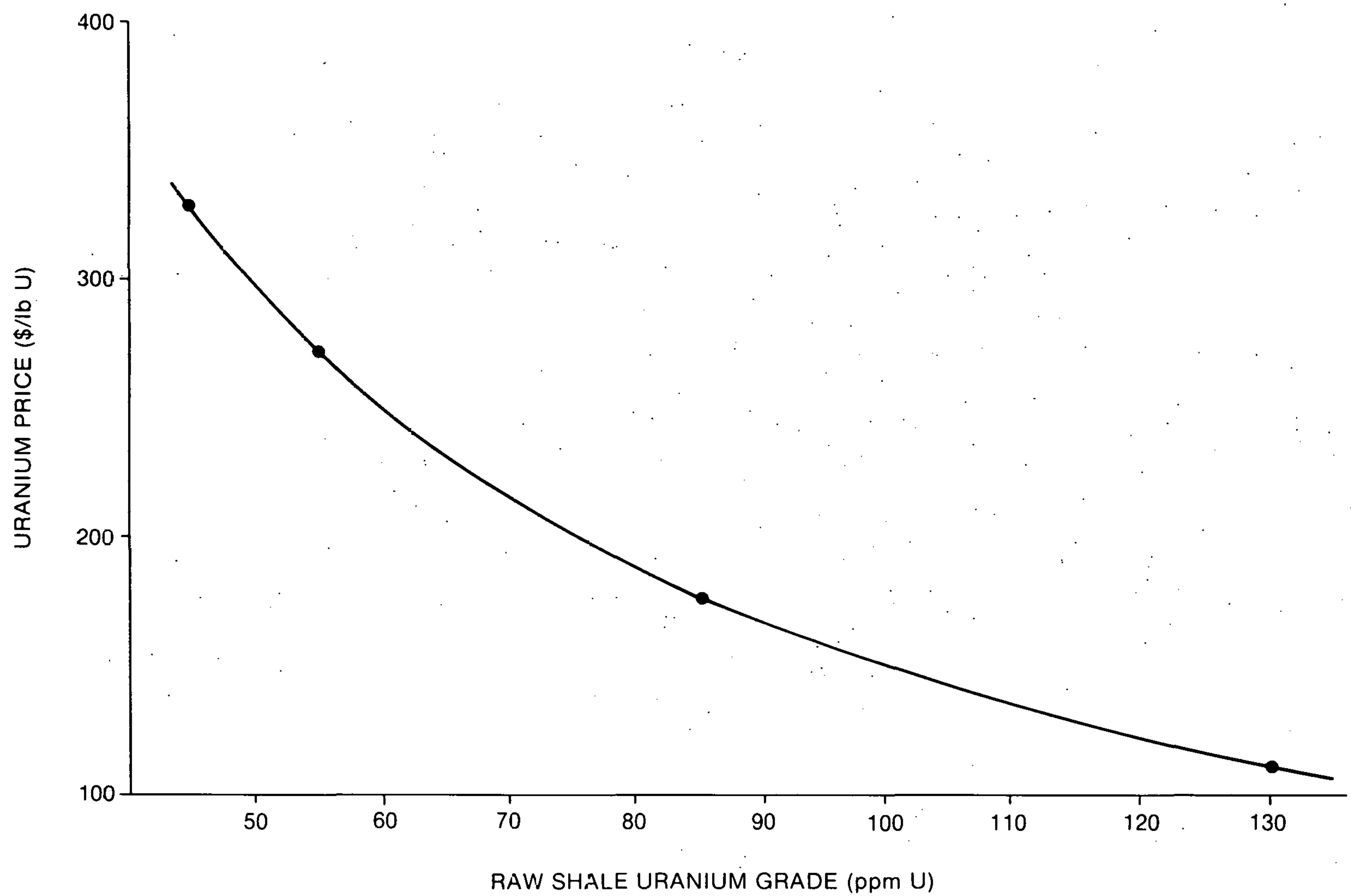


FIGURE V-4

SECTION VI
ANNOTATED BIBLIOGRAPHY

Abel, J.F. and W.N. Hoskins. "Confined Core Pillar Design for Colorado Oil Shale." Quarterly of the Colorado School of Mines 71(4):287-308. 1976.

The design of oil shale mine pillars, using the confined core concept, depends on the engineering properties of intact rock specimens, modified by factors in observed pillar failure. Ultimate failure occurs as shale-on-shale sliding along initial failure surface.

Agapito, Jose F. "Rock Mechanics Applications to the Design of Oil Shale Pillars." Mining Engineering. pp. 21-25. May, 1974.

Described in part is a geotechnical program instrumental in obtaining information for the design of large oil shale pillars. Study represents a joint effort during 1971/72 in the experimental mine of the Colony Development Operation formed by Atlantic Richfield Co. operator, the Oil Shale Corp., Cleveland-Cliffs Iron Co., and Sohio Petroleum Co. to conduct research and development in mining and retorting of oil shale. The mine is located at the southern edge of the Piceance Creek basin in N.W. Colorado.

Allsman, P.T. "A Simultaneous Caving and Surface Restoration System for Oil Shale Mining." Quarterly of the Colorado School of Mines. 63:113-126. 1968.

Introduces a concept comprising a modified caving method for mining oil shale and simultaneous restoration of the land surface by return of spent shale onto the subsided area.

Anderson, A. "Uranium Recovery from Bituminous Shales at Ranstad." Reprint from Uranium Ore Processing. International Atomic Energy Agency, Vienna. pp. 171-177. 1976.

Processes have been developed at this plant since 1968 for treating this relatively low grade, open pit-mined shale. Circuits and methods are described. Much study has gone into the disposal of tailings to prevent seepage pollution of groundwater.

Anderson, Ake and Gunnar Olsson. "Uranium Recovery from Swedish Low Grade Bituminous Shales." Nuclear Engineering International. 20 (225):103-105. 1975.

Lower grade uranium ores will become increasingly important in the 1980's. Sweden, except for current problems of approval from neighboring farmers who have sanction authority, has the potential at Ranstad to become a large scale producer. Since first interest in the 1950's much of the technology for shales in Sweden has been developed at Ranstad.

Baillod, C.R. and G.R. Alger. Storage and Disposal of Iron Ore Processing Waste Water. U.S. Environmental Protection Agency, Technology Series EPA-660/2-74-018. 1974. 135 pp.

Objective was to improve technology of storage and disposal of wastewater resulting from the concentration of low grade iron ore. Involved laboratory and field studies were conducted at the impoundment as well as clarification sites at Empire and Republic mines in the Peninsula of Upper Michigan.

Bates, T.F. An Investigation of the Mineralogy and Petrography of Uranium-Bearing Shales. U.S. Atomic Energy Commission, NYO-7908. 1958.

A total of 280 samples were analyzed for total carbon, organic carbon, aliphatic and aromatic hydrocarbon, carbonate, total iron, iron oxides, pyrite, total silicates, quartz, kaolinite, illite, amorphous silicates, uranium, molybdenum, manganese, and quartz grain size. The data obtained were analyzed using correlation and factor analysis statistics. It is concluded that the compositions of the shales investigated are highly dependent on the geological factors of the environment.

Bates, T.F. and E.O. Strahl. Mineralogy and Chemistry of Uranium-Bearing Black Shales. U.S. Atomic Energy Commission, NYO-7907. 1958.

Objectives of this study were: 1) to obtain a large amount of precise mineralogical, petrographic, and chemical data on samples of black shale representing various geologic periods, geographic localities and amounts of uranium concentration; 2) to analyze and define the interrelationship between the many measured variables; 3) to interpret the results in light of present concepts with the hope of adding new information to all the factors.

Bates, T.E., O. Strahl and R.L. O'Neil. An Investigation of the Mineralogy and Petrography of Uranium-Bearing Shales, Analyses of Shale Samples. U.S. Atomic Energy Commission, NYO-7909. 1958. 79 pp.

Data in this report includes the analysis of 1,135 shale samples taken from 29 drill cores of 9 formations. The geographic location and geologic age of each shale formation is described and the source of each core is given. A description of the analytical methods employed is given in summary and references to more complete descriptions are made.

Battelle Columbus Laboratories. Environmental Considerations for Oil Shale Development. U.S. Environmental Protection Agency, Technology Series EPA-650/2-74-099. 1974. 114 pp.

Results of a preliminary literature survey of environmental considerations associated with the development of an oil shale industry in the U.S. confined to Colorado, Utah and Wyoming. The study includes: oil shale deposits, mining, pre-treatment processes, in situ, ex-situ retorting, refuse disposal, product treatment and usage. Likely technical and environmental problems are described.

Battelle Memorial Institute. The Recovery of Uranium from Chattanooga Shales, Final Report for November 15, 1952 to January 14, 1954. U.S. Atomic Energy Commission, Chemistry BMI 274. 1954.

A process for extracting uranium from Chattanooga Shale was developed. It comprised retorting the Shale at a temperature between 1000° and

1100° F, an oxidizing roast at 1000° F, leaching the roasted calcine in 2 to 4 percent sulfuric acid, separating the leached calcine from the pregnant leach liquor, and recovering the uranium by ion exchange.

________. Assessment of Environmental Aspects of Uranium Mining and Milling. U.S. Environmental Protection Agency, Technology Series EPA 600/7-76-036. 1976. 50 pp.

The program discussed has the objective of making a preliminary assessment of potential environmental impacts associated with mining and milling domestic uranium ores. All forms of pollution except radiation are considered. The program includes a review of the characteristics and locations of: domestic uranium reserves; mines and mining; mills; processing methods; and potential environmental effect of all aspects of these activities.

Battelle Pacific Northwest Laboratories. Assessment of Uranium and Thorium Resources in the U.S. and the Effect of Policy Alternatives. Supported by Office of Energy R&D Policy of the National Science Foundation. 1974.

There were twin objectives of analyzing the known United States uranium/thorium resources and determining the effect of various policy options on the availability of these resources. It was concluded, in general, that such resources in the U.S. are extensive, but better technology and higher prices are required for exploitation.

Bauder, D.W. Initial Feasibility Investigation of a Hot Gas-Mechanical Excavator for Oil Shale Application. Systems Research Div. III-4753, Sandia Laboratories, Albuquerque, N.M. Sand-75-0127. 1975. 22 pp.

A tool employing the combination of mechanical action and flow of hot gas has been proposed as an excavation device for oil shale. Small scale experiments with a high velocity, hot gas jet have determined relations between excavation rate, gas temperature, pressure and shale grade. The energy in-put required was unacceptably high for the amount of shale removed.

Beers, R.E. and C. Goodman. "Distribution of Radioactivity in Ancient Sediments." Bulletin of the Geological Society of America 55:1229-1253.

By the use of beta-ray counters a method was developed for the determination of the three radioactive constituents in ancient sediments: potassium, thorium, and uranium. The highest concentration of all three radioactive constituents was found in the Antrim formation of Mississipian Age in Michigan. Similar characteristics were observed in the Chattanooga formation from wells in Oklahoma. Certain relationships were concluded as to occurrence of radioactivity and rock type.

Bell, K.G. Deposition of Uranium in Salt-Pan Basins. U.S. Geological Survey, Professional Paper 354-G. 1960a. 10 pp.

Drainage waters carry minute quantities of uranium into oceans, inland seas, and lakes. When bodies of water evaporate completely in desiccating salt-pan basins, the uranium must be deposited. Highly soluble uranium salts remain in solution and are deposited only as the basin finally is completely desiccated, but are not likely to be preserved because they are subject to removal by erosion or leaching. However, where organic rich muds, clays and sediments are present, the uranium may be adsorbed on them.

________. Uranium and Other Trace Elements in Petroleum and Rock Asphalts. U.S. Geological Survey, Professional Paper 356-B. 1960b. 20 pp.

Crude oil is not a practical source material for uranium; the total uranium content of the crude oil reserves of the U.S. does not exceed 5 tons. The bitumens of the rock-asphalt deposits of the U.S. contain several hundred tons of uranium, but because these bitumens are dispersed in several billion tons of rock they are not a practical source of uranium.

Bieniewski, Carl L., Franklin H. Persse, and Earl F. Brauch. Availability of Uranium at Various Prices from Resources in the United States. U.S. Bureau of Mines, IC 8501. 1971. 92 pp.

In a Bureau of Mines supply evaluation, the known uranium resources in the U.S. are estimated to have a total recoverable U_3O_8 content of 3,132,400 tons at prices up to $69.32 per pound. A total of 2,726,900 tons of U_3O_8 is available from: copper leach solutions, wet-process phosphoric acid, Florida leached zone, and Chattanooga Shale. The 1971 price of $8 is currently unrealistic.

Blair, B.E. Physical Properties of Chert, Shale and Limestone from the Pine Creek and Sligo Sites in DeKalb County, Tenn. U.S. Bureau of Mines, Report No. E 12.2 (E1-99). 1954. 42 pp. (Later combined with others to make: RI 4459 (Part 1), RI 4727 (Part II), RI 5130 (Part III), RI 5244 (Part IV). E 12.2 appears much abbreviated in Part IV.

The rock core was taken from two sites -- Pine Creek and Sligo, both in DeKalb County, Tennessee. Rock types tested were Fort Payne Chert, the Maury, Black Shale, and Dowelltown of the Chattanooga Shale and the Chickamauga Limestone. Physical properties required for underground mine opening and pillar design are discussed.

________. Physical Properties of Mine Rock, Part IV Including Indexes to Parts I, II, III and IV. U.S. Bureau of Mines, R.I. 5244. 1956. 6 pp.

Summary of detailed work done previously by Blair in 1954 on testing the physical properties of Chattanooga Shale. See Blair [1954] previously issued as USBM RI 6244 in 1956 in four parts; much abbreviated - this is part IV.

Bown, R.W. and R.H. Williamson. "Domestic Uranium Requirements." Presented at the Uranium Industry Seminar, Grand Junction, Colorado. Sponsored by the U.S. Department of Energy. October 26, 1977.

The record shows that each year since 1974 energy and electricity forecasters have lowered their sights. This latest current estimate, Table 3, indicates a 1990 uranium requirement of only 47,000 tons U_3O_8 compared to 99,000 tons in previously used reference, U.S. Atomic Energy Commission [1974].

Brill, K.G. Jr. and J.M. Nelson. Trace Elements Investigations-Hickman and Adjacent Counties, Tennessee. U.S. Geological Survey, Trace Elements Investigations Report #8. 1944. 39 pp.

This report lists some of the early data, probably 1944, and is not well organized. Appendix B shows some good measured seam thickness. Table 2 is a chemical analysis, 19 compounds, of one shale sample from Linden, Tennessee. Analysis was made by J.G. Fairchild of USGS with two determinations by F.S. Grimaldi.

Brown, Andrew. Experimental Adit in the Chattanooga Shale. 1949. 41 pp.

Objectives of the adit in the Gassaway member of the Chattanooga Shale were to obtain large (12-15 ton) samples of fresh rock for large scale laboratory tests and to obtain information on mining conditions, such as drilling, blasting, breakage, floor and roof conditions, and the mining characteristics of the Maury formation directly overlying the shale.

________. "Uranium in the Chattanooga Shale of Eastern Tennessee." Paper presented at International Conference on the Peaceful Uses of Atomic Energy. June 14, 1955. 10 pp.

The uraniferous Chattanooga Shale is part of a widespread blanket of bituminous shales of Late Devonian and Early Mississippian Age deposited over a large area in Tennessee and adjoining states. In 1942, reconnaissance of the Chattanooga Shale around the Nashville Dome, Tennessee, showed that the Shale is much more radioactive than other rocks in the area.

________. Uranium in the Chattanooga Shale of Eastern Tennessee. U.S. Geological Survey, Professional Paper 300. 1956. 6 pp.

The Chattanooga Shale contains in places sufficient uranium to make it a potential low-grade ore. The most promising areas are the Eastern Highland Rim in Tennessee. The shale is of Late Devonian Age with the top or Gassaway member being of interest with 0.005 to 0.008 percent uranium.

Brown, Andrew and I. May. Preliminary Report on Economic Potential of the Chattanooga Shale in Tennessee-Data as of 1962. Also, a section by May, The Precision of Determination of Uranium in Chattanooga Shale. U.S. Geological Survey, Open File Report 73-135. 288 pp.

In the course of investigations, routine analysis of the Chattanooga Shale, and studies to find answers to specific problems, much analytical and related data were obtained. This report is an attempt to summarize this information and put it in perspective for further use. A section discussing the precision of determination of uranium in Chattanooga Shale is included.

Cameron Engineers Inc. A Technical and Economic Study of Candidate Underground Mining Systems for Deep, Thick Oil Shale Deposits. Final Report-Phase II. 4 Volumes Prepared for U.S. Bureau of Mines. 1976. 329 pp.

A variety of engineering, production, and cost information is provided on 4 different mining systems investigated and evaluated for mining oil shale and other minerals in the Piceance Creek Basin of northwestern Colorado. Technical and economic feasibility was indicated over part of the range of requirements and under certain operating and market conditions.

Campbell, Guy. "New Albany Shale." Bulletin U.S. Geological Society. 57:829-908. 1946.

The New Albany Shale in Indiana consists of Devonian and Mississippian formations, based upon floral and faunal content. These beds continue through Kentucky, Ohio, and Tennessee. The Chattanooga in Tennessee contains equivalents of all the Indiana New Albany divisions.

Campbell, J.A., Editor. Short Papers of the U.S. Geological Survey-Uranium-Thorium Symposium-1977. U.S. Geological Survey, Circular 753. Papers presented at the Colorado School of Mines, Golden, Colorado. April 27-28, 1977.

This circular contains expanded abstracts for technical papers presented. Readers interested in additional information are requested to contact authors directly. Titles of 41 papers are in the Table of Contents.

Carlsson, Owe. "Uranium Production from Low Grade Swedish Shale." Stockholm, Sweden. L-A Nojd, AB Atomenergi, Studsvik, Sweden.

Low-grade uranium deposits will become more important in the future. To illustrate the feasibility of producing uranium from low-grade ore, a description is given of the Swedish Ranstad uranium shale project. This report describes the deposit, mine, and the circuits used for recovering the uranium along with an appraisal of the environmental constraints and available by-products.

________. "Description of the Percolation Leach at Ranstad, Sweden." From the paper "Uranium Production from Low Grade Swedish Shale" presented at International Conference on Nuclear Power and Its Fuel Cycle, Salzburg. May, 1977.

The percolation leach in use at the Ranstad mill is performed as a counter-current process with four leaching and two washing stages. Operating conditions are detailed. A flow sheet is appended with explanations.

Chang, Y.I., C.E. Till, R.R. Rudolph, J.R. Dean, and M.J. King. Alternative Fuel Cycle Options: Performance Characteristics and Impacts in Nuclear Power Growth Potential. Argonne National Laboratory, ANL 77-70. 1977. 42 pp.

The fuel utilization characteristics for LWR, SSCR, CANDU, and LMFBR reactor concepts are discussed from the standpoint of various fuel cycle options, including once-through cycles, thorium cycles, and denatured cycles.

Cochran, W. Mine Subsidence-Extent and Cost of Control in a Selected Area. U.S. Bureau of Mines, IC 8507. 1971. 32 pp.

The extent of damages caused by recent underground mining of coal in western Pennsylvania and ensuing surface subsidence were estimated in order to evaluate alternative cost effects. Costs are highest in areas where urban and suburban land use conflicts with mining. Potential subsidence damage from future mining exists in varying degrees in many parts of the U.S.

Colorado School of Mines. "Proceedings of the Ninth Oil Shale Symposium." Colorado School of Mines Quarterly. 71(4). 1976.

Nineteen papers by different authors relating to oil shale technology are presented; five papers to pertain to cultural resources and archaeology.

________. Mining Technology Research - 1975. U.S. Bureau of Mines, NTISPB 252-903.

Description of the programs, objectives, and accomplishments of the Bureau of Mines research program in the area of mining technology.

Conant, Louis C. Preliminary Summary Report on Chattanooga Shale Investigations (With Maps). U.S. Geological Survey, Trace Elements Memorandum Report 781. 1954. 27 pp.

In the Youngs Bend area 36 cores from holes with an average spacing of about 1 mile yielded uranium analyses indicating uranium content ranging from 0.0054 to 0.0067 percent, averaging 0.0060. Farther north, the shale contains less uranium, but for 40 miles to the south along the Eastern Highland Rim the shale seems to contain fully as much uranium. On the Northern Highland Rim no place has been found where the thickness and grade are comparable to that on the Eastern Highland Rim.

Conant, L.C. and V.E. Swanson. Chattanooga Shale and Related Rocks of Central Tennessee and Nearby Areas. U.S. Geological Survey, Professional Paper 357. 1961. 91 pp.

The Chattanooga Shale and the Maury formation, with a combined thickness of about 35 feet, outcrop on the steep slope between the Nashville Basin and the surrounding Highland Rim. It is part of a blanket of black shale deposited in a sea that covered large parts of America in Late Devonian time. There are several possibilities for future utiliziation for oil and by-products.

Cook, C. Wayne. Surface Rehabilitation of Land Disturbances Resulting From Oil Shale Development. Environmental Resources Center, Colorado State University, Ft. Collins, Colorado. 1974. 56 pp.

The Piceance Basin surface area is described in terms of the variations in ecology and its generally fragile nature. Assessment of problems caused by shale mining are made. Areas of inadequate knowledge are considered. Recommendations for improving knowledge and general solution of some of the problems are made.

Craig, John and Jacek Libicki. "Environmental Protection in Open Pit Coal Mining." Proceedings of the Polish-U.S. Symposium, Denver, Colorado. 5/27-29/75. Sponsored by U.S. Environmental Protection Agency. Published by University of Denver Research Institute. 1975. 169 pp.

Contains 18 papers on open pit coal mining techniques, refuse disposal, hydrology, water purification, runoff, sediment control, uses of fly ash, toxicity of water, waste stabilization, use of by-products, dewatering techniques, and surface reclamation. Papers pertain to both Polish and U.S. operations.

Crookston, R.B. and J. Merino. "Reclamation of Spent Oil Shale." Presented at the 1977 Mining Convention, American Mining Congress, San Francisco. September 11-14, 1977.

Critics of the oil shale industry claim that revegetation of the huge areas of retorted oil shale (spent shale) is not possible. Tosco has spent a decade studying the properties and problems of this material and has developed knowledge and techniques to reclaim such areas. Techniques are now under study for backfilling the material in underground workings.

Culbertson, W.J. Jr. and T.D. Nevens. "Disposal of the Oil Shale Ash." Quarterly of the Colorado School of Mines 65 (4):89-132. 1970.

Exhaustive laboratory tests on several different retorted oil shales were conducted to study soil mechanics of the material. Data relating to compressibility, moisture, cementing agents, burning temperature effects, dump stability, and leaching are graphed and discussed. Recommendations as to storage methods are made.

Dean, Basil G. Selected Annotated Bibliography of Uranium-Bearing Veins in the U.S. U.S. Geological Survey, Bulletin 1059-G. 1960. 114 pp.

This bibliography of 211 annotated references lists reports available as of June, 1957. An index map shows the location of vein deposits noted in the bibliography.

Department of Conservation State of Tennessee, Division of Geology.

Geological Maps, 7-1/2 minute, 1:24000 scale. Mineral Resources Summary. These quandrangles: Alexandria, Auburntown, Burgess Falls, Cassville, Campaign, Center Hill Dam, Doyle, Dibrell, Dry Valley, Gassaway, Hollow Springs, Liberty, Monterey Lake, Noah, Ovoca, Sampson, Short Mountain, Silver Point, Sligo Bridge, Smithville, Sparta, Spencer, Welchland, Woodbury.

Earnest, H.W., V. Rajaram, and T.A. Kaupilla. "Underground Disposal of Retorted Oil Shale." In: Proceedings of 10th Oil Shale Symposium. Golden, Colorado. pp. 213-222. 1977.

Methods for underground disposal of retorted oil shale were investigated. Methods include transport and stowing by hydraulic, mechanical, and pneumatic means for a deep mine in the Piceance Basin. Mechanical transport and stowing was determined to be best on subjective and objective technical analysis. Accompanying letter regarding hydraulic fill should be read, however.

East, J.H. Jr. and E.D. Gardner. Oil Shale Mining, Rifle, Colo., 1944-1956. U.S. Bureau of Mines, Bulletin 611-1964. 163 pp.

The Rifle, Colorado oil shale project of the USBM was a facet of R&D conducted under Synthetic Liquid Fuels -4/5/44. This report gives complete data and history on mining. The two other major Divisions are the Retorting and Refining. Development of methods and equipment are discussed with objectives met, 148 tons per man-shift underground at a direct cost of $0.30 per ton.

Engineering and Mining Journal. "News Brief." Engineering and Mining Journal. pp. 135-6. December, 1977.

As a result of rejection of plans to mine 1 million MTPY in Billingen area, a new company, Svenska, was formed to Stal AB, a combination of steel companies, railway, ports, and government. It will have a capacity of about 4 million MTPY.

Energy Research and Development Administration. Resources, Fuel and Fuel Cycles, and Proliferation Aspects. ERDA 77-60. 1977. 38 pp.

The report discusses alternative fuel cycles and their respective proliferation aspects. New technology and regulatory procedures necessary for safeguarding against diversion is suggested.

Ensign, C.O. Jr. "White Pine, an Innovative, Hard Rock, Underground Mine." In: Proceedings of Conference on Productivity in Mines. University of Missouri, Rolla, Missouri. pp. 52-71. 1974.

In the mining industry "Innovative Productivity Advances--or Die!" is the law of survival. White Pine mine is described as an example of the philosophy. Accomplishments in productivity gains which could be helpful in mining coal and/or oil shale are described. Opportunities for further improvements are presented.

Eschbach, E.A. "Plutonium Value Analysis." Proceedings of the Third International Conference on the Peaceful Uses of Atomic Energy. Volume 11: Nuclear Fuels II - Types and Economics. Geneva. 1964.

A discussion of the economic value of plutonium fuel which is normally a by-product without assignable cost. The approach is to determine its value as a recycled fuel in the parent reactor.

________. Crossed Progeny and Some Other Nonstandard Fuel Cycles. ANS Winter Meeting, San Francisco. 1977. 40 pp.

This paper discusses a system of two different reactors with cross utilization of reactor products for better resource utilization and maintenance of fissile fuel supplies. It also provides high performance LWR fuel that is fully denatured.

Finch, W.I. Geology of Epignetic Uranium Deposits in Sandstone in the U.S. U.S. Geological Survey, Professional Paper 538. 1967. 121 pp.

Epignetic uranium deposits in sandstone and related rocks are formed by the precipitation of uranium minerals from solutions. These deposits are widespread in the U.S.; they have yielded most of the uranium ore produced here and contain nearly all the domestic ore reserves. The different types of deposits and occurrences are discussed.

Finger, M. and D. Larson. "Use of Explosives in Deep Rock Mining: In Situ Energy and Mineral Recovery." Presented at meeting of the Society of Explosives Engineers, Morgantown, W. Va. January 28-30, 1976. Preprint UCRL-77721.

Chemical explosives may become a key element in many of the in situ energy and mineral recovery methods under development. This paper discusses the potential role of explosives in deep rock mining.

Frondel, Clifford. Systematic Mineralogy of Uranium and Thorium. U.S. Geological Survey, Bulletin 1064. 1958. 399 pp.

Uranium and thorium minerals plus a few rare-earth minerals containing minor amounts of uranium and thorium are systematically and comprehensively described. The work is documented by more than 800 references to the world literature of the past 200 years. The classification included here is chemical in the following broad categories: oxides, carbonates, sulfates, molybdates, phosphates and arsenates, vanadates, silicates, and the multiple oxides. Crystal habit, physical optical properties, occurrence, etc., are also described.

Fulton, Linda. "Stratigraphy and Sedimentology of Radioactive Devonian-Mississippian Shales of the Central Appalachian Basin." Dissertation to University of Cincinnati. 1977. 177 pp.

In eastern Kentucky the Ohio Shale, a radioactive black organic-rich shale of Late Devonian Age, consists of two dominant lithologic types along with 5 to 7 subunits which can be recognized over most of eastern Kentucky and parts of Ohio, West Virginia, and Tennessee. In descending order these subunits are: Cleveland Shale; Three Lick Bed, Upper, Middle and Lower Huron Shales; Olentangy Shale; Marcellus(?) Shale. The first five of these units are correlatable with members of the Ohio Shale in Ohio and with members of the Chattanooga Shale of Tennessee.

Funk, Erwin D. "Process and Apparatus for Conveying Large Particle Mined Coal, Oil Shale, Ore, etc. from Underground Mines or from Strip Mines via a Pipeline." U.S. Patent 3,982,789. Sept. 28, 1976. Assignee: Kamyr, Inc., Glens Falls, N.Y.

________. "Preliminary Reconnaissance for Uranium in Arkansas, Illinois, Kentucky, Michigan, Minnesota, Missouri, Ohio, and Wisconsin, 1952-1956." Atomic Energy Commission, RME 150-Geology and Minerology (TID 4,500).

A detailed listing of each sample site as to important aspects such as location, kind of sample, name of property owner, sample size, etc.

Gardner, E.D., A.A. McKinney, and P.L. Russell. Preliminary Report Chattanooga Shale Project to the Atomic Energy Commission. U.S. Bureau of Mines. 1954. 42 pp.

Studies by the USBM of the Chattanooga Shale show that the more favorable areas of interest for uranium content lie within the state of Tennessee. A weak and barren shale overlies the Chattanooga. One favorable area is that at Youngs Bend in DeKalb County where the shale is 15.2 feet thick and contains 60 ppm uranium. There are 206 billion tons of minable shale containing 12,400 tons of uranium.

Glover, Lynn. Stratigraphy and Uranium Content of the Chattanooga Shale in Northeastern Alabama, Northwestern Georgia, and Eastern Tennessee. U.S. Geological Survey, Bulletin 1087-E. 1959. 46 pp.

The region studied encompasses N.E. Alabama, N.W. Georgia, and E. Tennessee where the Chattanooga Shale of Late Devonian ranges in thickness from 0 to 40 feet. The Maury, Mississippian is usually present. Occasional influxes of greater than usual amounts of inorganic material produced the gray beds common in the Chattanooga.

Gruner, John W. "Concentration of Uranium in Sediments by Multiple Migration-Accretion." Economic Geology 51(6):495-520. 1956.

The continual expansion of areas in which uranium finds are being reported in sedimentary rocks makes the hypothesis that the metal was transported by solutions hydrothermal in origin entirely inadequate. Weathering and erosion of over 400 million tons of Precambrian granitic rocks since Pennsylvanian time provides the source of the uranium leached by the action of bicarbonates of Ca, Mg, and Na in a CO_2-saturated solution. When reducing conditions exist along the migration channels the black ores of uranium are precipitated. Over long periods much "recycling" of the process would continue, under the right conditions.

________. "The Why and Where of Uranium in Sedimentary Rocks." The Mines Magazine. pp. 84-88. March, 1957.

A discussion of almost universally encountered geologic conditions of uranium concentration in the western U.S.: 1) they are in non-marine continental type sediments; 2) they are commonly in relatively coarse, poorly sorted rocks; 3) uranium deposition often occurs at contacts between coarse and fine, silty layers; 4) mudstones and silts are of importance in most uranium settings; 5) the rocks in which the black uranium ores occur are usually gray to white; 6) carbonaceous matter is almost always present; 7) pyrite or marcasite is always present in unoxidized uraniferous beds; 8) the iron sulfides, on oxidation, cause the rocks to turn buff or brown.

Grutt, Eugene W. Jr. "Uranium Exploration Methods Development." Mining Congress Journal. pp. 60-67. April, 1977.

Improved technology is being developed to support exploration by industry and the on-going Uranium Resource Assessment Program. These range from modest improvements on established methods to new sophisticated systems for direct uranium logging using neutron interrogation. Predictions for 1985 call for nuclear plants totaling 145,000 mw to be in operation.

Hickman, R.C. and V.J. Lynch. Chattanooga Shale Investigations. U.S. Bureau of Mines, RI-6932. 1967. 55 pp.

Preliminary evidence indicated the Chattanooga Shale as a vast low-grade potential source of uranium. Core drilling indicated a very low grade, 60 ppm uranium resource. The Appendix includes drillers logs of many cored holes.

Institute of Gas Technology. Program Plans for the Development of the IGT Oil Shale Process. Institute of Gas Technology, Chicago, Illinois. 1973. 37 pp.

IGT has developed a greatly improved process for direct conversion of oil shale to selective co-products, i.e., middle-distillate-type oil and/or substitute natural gas. Ninety-five percent of the organic carbon can be recovered. Progress is such that work could be accelerated. A proposed program of 7 years at a cost of $40 million would culminate in a design of a commercial-sized demonstration plant including construction and operation of a 10 ton/hour shale feed rate pilot plant.

________. Eastern Oil Shale-A New Resource for Clean Fuels. Institute of Gas Technology, Chicago, Illinois. 1977. 19 pp.

Devonian shales of eastern U.S. can be processed with a new method to yield up to 2-1/2 times as much oil as had previously been expected. The process can be regulated to produce oil, gas, or both. It is estimated that 423 billion barrels of oil could be thus obtained by mining the croplines of the eastern shales.

Jankousky, C.K. "Disposal of Coal Refuse Slurry Underground." Presented at Coal Convention of American Mining Congress, Pittsburgh, Pennsylvania. May 1-4, 1977. 11 pp.

Discussed is a method for disposing of fine coal refuse by hydraulic transportation underground at Orient 4 mine in southern Illinois.

Correct geologic conditions and an adaptable mine plan are required. Surface disposal will become increasingly expensive because of the land cost.

Kehn, T.M. Uranium in the Chattanooga Shale, Youngs Bend Area, Eastern Highland Rim, Tennessee. U.S. Geological Survey, TEI-528-A. 1955. 60 pp.

In December, 1952 a diamond drilling project was undertaken to obtain geologic and mining information and core samples of the uranium-bearing Chattanooga Shale near Smithville, Tennessee. Thirty cores from this area indicate 15-foot thickness in 21 square miles with an average content of 0.0060 percent uranium. This is 620 million tons of shale or 38,000 tons of uranium. Additional widespread holes along the Eastern Highland Rim indicate similar characteristics for about 50 miles south of Smithville.

Kentucky Department for Natural Resources and Conservation. Debris Basins for Control of Surface Mine Sedimentation. U.S. Environmental Protection Agency, Technology Series EPA-600/2-76-108. 1976a. 47 pp.

Report presents the feasibility of the use of debris basins in controlling solids in water discharging from surface mine operations. Pertinent site information including flow and water quality data was gathered.

________. Institute for Mining and Minerals Research. Proceedings-Second Kentucky Coal Refuse Disposal and Utilization Seminar. Held at Pine Mountain State Park, Pineville, Kentucky. 1976b. 114 pp.

The content of these papers indicates a growing awareness that coal refuse can and should be analyzed and evaluated as an engineering material and utilized as appropriate. Evaluation must be based on its characteristics and properties. Potential for being processed into useful materials appears promising.

Kissell, Fred N. "The Potential Hazards of Methane Gas in Oil Shale Mines." Quarterly of the Colorado School of Mines 70(4):19-29. 1976.

A Bureau of Mines technique for measuring the methane content of virgin coal beds by degassing exploration drill cores has been used to estimate the methane content of oil shales. It is doubtful this simple comparison will be successful, but it does appear that deep oil shale mines may have methane gas to contend with.

Klemenic, John. "Some Financial Aspects of the Domestic Uranium Mining and Milling Industry Over the Next Fifteen Years." Paper presented at AEC Uranium Industry Seminar, Grand Junction, Colorado. October, 1972. 43 pp.

This paper presents a financial analysis of the uranium industry. Most of the cost data are in the form of yearly dollar expenditures. Cost data represent "forward" costs as of January 1, 1973. The costs represent those associated with the $8/lb cost.

________. "An Estimate of the Economics of Uranium Concentrate Production from Low-Grade Sources." Paper presented at AEC Uranium Industry Seminar, Grand Junction, Colorado. October, 1974. 36 pp.

This study is to recognize significant changes in prices of U_3O_8 that have occurred and the effects of those higher prices on the possibilities for using lower grade ores. This study presents typical results as cash-flow rate of return on a range of prices for U_3O_8.

Kroft, David J. "Future Uranium Supplies vs. Demand-The Strategic Position of the U.S." In: Dames and Moore Engineering Bulletin 49, Sources of Energy-Part 1: Uranium. 1977. 49 pp.

The author attempts to more clearly define the true demand/supply relationships with varying uranium content in the resources, price, and varying modes of energy use in the U.S. Alternate overseas supplies are assessed and appraised as to future accessibility to the U.S., given the changing economic and political climates. The best interests of the U.S. are served in attempting to secure additional sources both here and abroad to ensure the necessary future needs.

Krusiewski, S. Victoria. Availability of U.S.A.E.C. Geology-Mineralogy Reports. U.S. Atomic Energy Commission. 1973. 124 pp.

This is a bibliography of these types of reports by the U.S. Atomic Energy Commission. Location, availability, and price in 1973 are disclosed.

Larson, W.C. The State of the Art of In Situ Leach Mining, F.Y. 77. Twin Cities Mining Research Center, U.S. Bureau of Mines, Minneapolis. 1977.

A comprehensive statement of the art and science of in situ mining describing favorable conditions for its success.

Leach, H.J. "Analysis of Methods for Underground Mining of Oil Shale." Mining Congress Journal. 1975. 6 pp.

Domestic oil shales have been of interest since 1850 as a source of oil. Economics of the oil industry have never made recovery feasible until the embargo of 1973. Large mines, large equipment, minimum cost mining methods will someday make exploitation possible. Present methods are reviewed with a forecast for successful solution of certain future problems.

Lootens, Douglas J. "Uranium Production Methods and Economic Considerations." In: Dames and Moore Engineering Bulletin 49, Sources of Energy-Part 1: Uranium. 1977. 49 pp.

The paper describes and appraises a number of mining and processing methods in current use, their approximate costs, and the economic implications of each. Also described are novel uranium recovery systems such as those from large copper mines and from phosphate mining-processing systems.

Marshall, Paul W. "Colony Development Operation Room-and-Pillar Oil Shale Mining." Quarterly of the Colorado School of Mines 69(2):171-184. 1974.

Colony Development Operation is a joint venture of four active members: The Oil Shale Corp (TOSCO); Atlantic Richfield Co.; Ashland Oil Inc.; Shell Oil Co. This project is for underground mining of 66,000 tons per day, retorted on site which is on Parachute Creek in the Piceance Basin, Colorado, 200 miles west of Denver.

Martin, H.W. and W. Mills, Jr. Water Pollution Caused by Inactive Ore and Mineral Mines - A National Assessment. U.S. Environmental Protection Agency, Technology Series EPA-600/2-76-298. 1976. 185 pp.

The report identifies the scope and magnitude of water pollution from inactive ore and mineral mines. Data collected from Federal, State, and local agencies indicate water pollution from acids, heavy metals, and sedimentation occurs at over 100 locations affecting over 1,200 kilometers of streams. Annual pollutant loading rates are given. Also provided is a method to determine the extent of mine-related sedimentation in western watersheds.

Matzie, R.A. and J.E. Rec. "Assessment of Thorium Fuel Cycles in Pressurized Water Reactors." Presented at International Conference on World Nuclear Power, Washington, D.C. 1976.

A discussion of efficiency of uranium ore resource utilization through employment of improved cycles and reactor designs.

Mentz, J.W. and J.B. Warg. Up-Dip Versus Down-Dip Mining, An Evaluation. U.S. Environmental Protection Agency, Technology Series EPA-670/2-75-047. 1975. 72 pp.

This report presents results of a feasibility study of down-dip mining, a technique that appears to offer an alternative to sealing or permanent treatment of polluted effluent from coal mines after abandonment.

Miller, J.S. and H.R. Nicholls. Methods and Evaluation of Explosive Fracturing in Oil Shale. U.S. Bureau of Mines, RI 7729. 1973. 22 pp.

A program involving chemical explosives in several configurations of borehole location from the surface into oil shale to determine variables in the problem of fragmenting oil shale for in situ retorting gave interesting but inconclusive results. Further field application and development of evaluation technology are needed.

Mineral Beneficiation Laboratory. Analysis and Characterization of Oils Retorted from Chattanooga Shale by U.S.B.M., at Laramie, Wyoming. Columbia University, U.S. Atomic Energy Commission, RMO 4013. 1957. 55 pp.

This report is an evaluation of Chattanooga Shale oils as possible resources or by-products of a uranium recovery process. Results are tabulated separately for four different retort temperatures. Retorting was done at Laramie by U.S. Bureau of Mines.

________. Recovery of Uranium From Chattanooga Shale. Cost Estimation of a Solvent Extraction Plant. Columbia University, U.S. Atomic Energy Commission, RMO-4016. 1959a. 58 pp.

This study is to provide a picture of the cost of uranium recovery from Chattanooga Shale leach liquors by solvent extraction. The process is outlined and defined in terms of important variables. Specific design procedures are given for process equipment and all equipment is sized. Parametric costs are formulated and combined into equations for the calculation of capital requirement and manufacturing cost. Costs are estimated for leach liquors.

________ Recovery of Uranium from the Chattanooga Shale. Cost Estimation of an Ion Exchange Plant. Columbia University, U.S. Atomic Energy Commission, RMO-4017. 1959b. 54 pp.

This report describes the process and details the flowsheet. Specific design procedures for process equipment are explained and equipment sized. Parametric cost expressions are formulated into equations for calculation of capital and manufacturing cost. Costs of leach liquors are estimated.

________. Recovery of Uranium From Chattanooga Shale. Final Report. Columbia University, U.S. Atomic Energy Commission, RMO-4015. 1960. 256 pp.

The objectives of this study were twofold: 1) to find one or more methods of beneficiating Chattanooga Shale for uranium; 2) to make a preliminary technico-economic evaluation of the process. The two most promising processes were: 1) counter-current leaching of raw shale with sulfuric acid; 2) oxygen pressure leaching in which leaching and acid production are simultaneously achieved. Mentioned is a promising but not at that time developed, method: high temperature chlorination.

Mining Engineering - Industry Newswatch. "Boliden, LKAB join forces to exploit Swedish alum shales after a plan to mine 1 million mtpy of alum shales at Billingen (Ranstad) was formally rejected by two southern Swedish town councils." Mining Engineering. pp. 14-15. December, 1977.

Sweden's two largest mining companies, Boliden AB and Luossavaara-Kiirunavaara AB (LKAB) have formed a joint development holding company, Aktiebolaget Svensk Alunskifferutveckling (ASA) to conduct prospecting, research, and development work relating to Swedish deposits of alum shales.

Mitre Corporation. Nuclear Power Issues and Choices. Report of the Nuclear Energy Power Group. 1977. 418 pp.

A classification of the issues underlying the debate on nuclear power. In the overview section of the book a summary of the authors assessment of the issues and the resulting conclusions and recommendations are presented. These conclusions have formed the basis for current U.S. policy on atomic energy.

________. Assessment of the Thorium Fuel Cycle in Power Reactors. ORNL/TM 5565. 1977. 181 pp.

A study of the role of thorium as a fuel in power reactors in the LWR, HTGR, and HWR cycles. In thermal reactors, thorium is shown to aid in U_3O_8 utilization but does not lessen the long-term need for FBR cycles. Thorium also offers the possibility of lower cost power than uranium (only) cycles.

Moomau, H.F. and F.R. Zacher. Feasibility Study of a New Surface Mining Method "Longwall Stripping." U.S. Environmental Protection Agency, Technology Series EPA-670/2-74-002. 1974.

This new method adapts existing underground long wall technology for use in recovering shallow cover coal without the total environmental disturbance associated with surface mining.

________. The Physical and Chemical Characteristics of Available Materials for Filling Subsurface Coal Mines. U.S. Bureau of Mines, Open File Report 151-77. 1977.

Samples were taken of a variety of industrial mineral wastes as potential for filling material in underground coal mines to control subsidence in the Pittsburgh and Scranton-Wilkes Barre areas of Pennsylvania. These materials were analyzed and measured. Possibilities of emplacement as liquid or mud were considered.

Moore, George W. Extraction of Uranium from Aqueous Solution by Coal and Some Other Materials. U.S. Geological Survey. 1954. 7 pp.

Uranium in nature is commonly associated with carbonaceous material. Laboratory studies were conducted to determine the relative abilities of various substances to remove uranium from an aqueous solution. Subbituminous coal extracted 99.9 percent; peat and lignite, 98 percent; canneloid coal, 80 percent; phosphate rock, 63 percent. These results suggest a possible use as a gathering mechanism of the uranium bearing waste streams.

Mutschler, Paul H., J.J. Hill, and B.B. Williams. Uranium from the Chattanooga Shale, Some Problems Involved in Development. U.S. Bureau of Mines, IC 8700. 1976. 85 pp.

In a 12-county area of Tennessee geologic data and chemical analyses from previous reports are assembled into a low-grade resource assessment of 76 to 91 billion tons of shale containing 4.2 to 5.1 million tons of uranium. A model was developed partially showing the environmental impact should the resource be exploited.

National Academy of Sciences. Mineral Resources and the Environment Supplementary Report: Reserves and Resources of Uranium in the U.S. 1975. 235 pp.

This COMRATE report concluded that current reserve data is reliable but estimates of potential resources are of uncertain validity. After 1980, lacking a breeder reactor, domestic uranium production may begin to fall short of demand. Beyond 1980 potential resources must be verified. Most serious obstacle is uncertainty as to future of nuclear power. Search for new reserves is hampered by inadequate understanding of controlling geologic processes. Need exists for expansion of joint effort of government and industry to develop new techniques for detection of hidden deposits.

National Cartographic Information Center. Aerial Photography Summary Record System Catalogs 2 & 3. U.S.G.S. May, 1975.

The National Cartographic Information Center has developed to replace former systems, the Aerial Photography Summary Record System (APSRS) to store and frequently display the status of aerial photography in the U.S.

Netzen, Gosta. Billingen, 4 Exempel. (In Swedish). Statins offentliga utredningar 1977:47. 1977. 282 pp.

This is a book describing four possible sites for processing facilities in Sweden.

Oak Ridge National Laboratory. Recovery of Uranium from Oil Shales-Part I: Extraction of Uranium from the Shale Gangue. 1950a. 155 pp.

This report presents a summary of the work carried out over a number of years to devise an acceptable recovery system of uranium from black shales. The method used was not piloted but is believed to be usable with further development. Most acceptable methods involved a controlled preliminary roast of the shale followed by a leach with dilute acid. Also tested was a direct leach with no roasting.

_______. Recovery of Uranium from Oil Shales-Part II: Recovery of Uranium from Acid Leaches of Shale. 1950b. 101 pp.

Precipitation of uranium in leach solutions was accomplished in several ways, but poor selectivity and low concentration of uranium ions contributed to copious precipitates containing only small amounts of uranium. The best of the processes tested consisted of precipitations of uranous phosphate from solutions of low pH.

Obert, L. and R. Merrill. Oil Shale Mine, Rifle, Colorado-A Review of Design Factors. U.S. Bureau of Mines, R.I. 5429. 1958. 13 pp.

From 1945 to 1956 the USBM operated an underground oil shale mine near Rifle, Colorado using a room-and-pillar system of mining. The roof support design had been based on data obtained from laboratory model studies. In the last 2 years of operation two roof falls occurred. This report reappraises the previous work and makes suggestions for planning future oil shale mining.

O'Neil, R.L. "A Study of Trace Element Distribution in the Chattanooga Shale." Thesis to Graduate School, Pennsylvania State University. June, 1956. 62 pp.

The concentration of certain trace elements in bituminous shales of marine origin is well established. The chalcophile nature of many of the elements concentrated in bituminous shales indicates that precipitation as sulphides may be an important factor in their enrichment. The presence of pyrite in black shale is significant. The role of organic material during sedimentation and diagenesis of bituminous shales has never been completely resolved. Statistical handling of analyses is discussed.

Parker, John. "What Can Be Learned from Surface Subsidence?-Part 2: Practical Rock Mechanics for the Miner." Engineering and Mining Journal. July, 1973. 4 pp.

Presented is a discussion with sketches of various types of subsidence and roof failure in mining flat-lying seams.

Peterson, A. "Ranstad-A New Uranium-Processing Plant." In: Processing Low-Grade Uranium Ores. p. 193-209. Inernational Atomic Energy Agency, Vienna. 1967.

A short outline is given of the decisions concerning the erection and operation of the Ranstad mill which had recently begun operation. Also described are the mining system, plant location, and mill facilities. The equipment and processes to treat 850,000 tons of shale per year are described. Operational experience is reviewed as is the economy of production. Some development possibilities are indicated.

Pfeffer, F.M. Pollution Problems and Research Needs for an Oil Shale Industry. U.S. Environmental Protection Agency, Technology Series EPA-660/ 2-74-067. 1974. 36 pp.

The stabilization of spent shale residue is the major environmental problem confronting the oil shale industry. Reclamation of the disposal site is second in priority to stabilization. Freeze-thaw conditions and water saturation can result in mass movement of spent shale, but this can be prevented. Process waters need not be a pollution problem.

Pohl, R.O. "Health Effects of Radon-222 from Uranium Mining." Search 7(8). 1976.

The emanation of radon-222 and its short-lived daughters from uranium mill tailings represents a substantial, and thus far largely neglected, health hazard in the nuclear fuel cycle. The discussion is based largely on "Environmental Analysis of the Uranium Fuel Cycle" a report by USEPA, 1973.

Rajaram, V., T.A. Kauppila, and R.L. Bolmer. "Oil Shale Mining and the Environment." The Second Pacific Chemical Engineering Congress. 1977. 15 pp.

The oil shale resources in Colorado, Utah, and Wyoming contain 1,842 billion barrels of oil of which only 610 billion are recoverable with current technology. The USBM commissioned Cleveland-Cliffs Iron Company to design a demonstration mine in deep, thick oil shale deposits in Colorado. The design of this mine using four different mining systems and the resultant environmental aspects are described.

Reynolds, W.J. Mining Considerations for In Situ Oil Shale Development. Lawrence Livermore Laboratory, UCRL-51867. 1975. 27 pp.

Mining considerations inherent to the in situ development of oil shale are examined. Three mining methods are evaluated for producing a rubble column. Physical and environmental constraints are discussed. Costs are estimated.

Robeck, R.C. and L.C. Conant. Reconnaissance Search in Parts of Kentucky, Tennessee, Indiana, Virginia, and Ohio for Areas where Uraniferous Black Shale May be Mined by Stripping. U.S. Geological Survey, Trace Elements Investigations Report 64. 1951. 35 pp.

The purposes of this investigation were: 1) to find one or more areas where at least 200 million tons of black shale could be economically stripped, and 2) to determine the uranium content of the shale in such areas. Those that appear best for stripping are in Kentucky where over 1 billion tons of black shale appear to be available, but this shale contains only about 10 to 40 ppm uranium, with an oil yield of perhaps 15 gallons per ton. Overburden is 40 to 100 feet thick.

Rothman, A.J. Promises and Problems in In Situ Oil Shale Development. Lawrence Livermore Laboratory, UCRL-76583. 1975. 10 pp.

A process is proposed for obtaining oil from oil shale underground by rubblization of a substantial portion of the deposit and retorting in place.

Russell, P.L. and A.A. McKinney. Alternate Experimental Mine Sites-Chattanooga Shale Project to the A.E.C. U.S. Bureau of Mines. 1954. 12 pp.

In March, 1954 the Bureau of Mines recommended an experimental minesite. Alternate sites have been requested. Four such sites are described in this report as well as the initial one. Four sites are in DeKalb County; the other is in Cannon County.

Schmidt-Collerus, J.J. The Disposal and Environmental Effects of Carbonaceous Solid Wastes from Commercial Oil Shale Operations. National Science Foundation, GI 34282X1. 1974. 247 pp.

Part 1 contains general background and a discussion of problems regarding the projected research program, with summaries of the physical aspects of shale retorting technology. Part 2 deals with the NSF (RANN) research program and aspects of its methods and problems. Part 3 discusses experimental data and preliminary

conclusions. Part 4 is a summary of the program objectives and projections of an extended research effort. A voluminous bibliography is included.

Schmidt, R.A. and C.W. Huddle. Fracture Mechanics of Oil Shale- Some Preliminary Results. Sandia Laboratories 76-0727. 1977. 29 pp.

Results of a comprehensive series of fracture toughness tests on oil shale from Anvil Points are presented. Fracture toughness was found to decrease by about 40 percent for an increase in kerogen content from 20 to 40 gallons per ton.

Schora, Frank. C. "Statement Submitted for the Hearing Record- Senate Subcommittee on Energy Research and Development. Fiscal Year Budget Authorization." April 5, 1977. 11 pp.

Research at the Institute of Gas Research began in 1956 on an improved process for extracting energy from oil shales. A new process, heating in the presence of hydrogen, can extract 35 percent more usable energy from Colorado Shale. Applied to eastern U.S. shales the newly developed hydroretorting process yields energy values almost as high as western shale yields, even though eastern shales have traditionally been considered poor candidates for oil supply. Devonian shales of the east have yielded 250 percent more oil than indicated by their Fischer assays. The vast existing tonnages of eastern Devonian shales provide an interesting resource for energy recovery.

Scott, D.W. and H. Adam. Mineral Composition and Mineral Association of Uranium in Shale. Battelle Columbus Laboratories, BMI-JDS-203. 1949.

This is an exposition of the minerals and associations of minerals of uranium in shale, but the study is difficult to quantify due to the extremely fine deposition of the uranium and consequent lack of discrete minerals.

Scott, R.C. and F.B. Barker. Data on Uranium and Radium in Ground Water in the United States 1954 to 1957. U.S. Geological Survey, Professional Paper 426. 1962. 115 pp.

From 1954 to 1957 uranium and radium concentrations were determined in 561 samples, mainly groundwater, having wide geologic and geographic distribution. These concentrations, together with data on the hydrologic and geologic environment, the beta-gamma activity, and the chemical characteristics of each sample, are tabulated by State. The conterminous U.S. was subdivided into 10 geotectonic regions to facilitate statistical interpretation of the occurrence of uranium and radium in fresh water in approximately homogeneous geologic provinces.

Sellers, J.B., G.R. Haworth, and P.G. Zambas. "Rock Mechanics Research on Oil Shale Mining." Society of Mining Engineers-Transactions 252. 1972.

Rock mechanics research was carried out in the Anvil Points mine, Rifle, Colorado, during the period 1964-68, with the dual purpose of providing oil shale to the retorts of six major oil companies and performing research on mining cycle operations to maximize extraction under safe conditions. An 80 percent extraction within the mining area proved feasible. Test results provided data on optimum pillar and mine opening design.

Shaw, K. Glenn. Recovery of Uranium From Phosphate Rock During the Manufacture of Wet Process Phosphoric Acid. Research Report. Dow Chemical C mpany, DOW 111. 1954. 21 pp.

Results of an investigation on the recovery of uranium dissolved into the acid phase during the manufacture of wet process phosphoric acid are reported. Several means of decreasing uranium losses to the gypsum are presented.

Sims, W. Norman. Borehole Hydraulic Mining. Marconaflow, Inc. 1976. 24 pp.

Presented are a technique and equipment for putting surface stored particles into a liquid suspension for pipeline transfer or transportation; also discussed is a possible adaptation of that system to underground mining through boreholes for adaptable material.

Snyder, Geo. A., F.A. Zuhl, and E.F. Burch. "Solidification of Fine Coal Refuse." Mining Congress Journal. December, 1977. 4 pp.

A principal technical difficulty in coal production is the safe, economic disposal of fine refuse (0x28 mesh) because of its adverse effect on the environment. Impoundments to contain it are expensive and difficult to maintain and use. Calcilox additive by Dravo can produce a solidified mass with dependable engineering properties. These are described.

Society of Mining Engineers. "United Nuclear-Homestake Partners Recover U_3O_8 Via Alkaline Leaching." Mining Engineering. 1974. 3 pp.

Describes a 3,500 feed tons/day operation at Grants, New Mexico, using a Na_2CO_3 leach circuit for the recovery of uranium rather than the H_2SO_4 leaching method common in the area. This makes it possible to precipitate yellowcake directly from the leach solution rather than through ion exchange or solvent extraction circuits.

Sprute, R.H. and D.J. Kelsh. Laboratory Experiments in Electrokinetic Densification of Mill Tailings-1. Development of Equipment and Procedures. U.S. Bureau of Mines, RI 7892. 1974. 72 pp.

This report describes the Bureau of Mines laboratory test results in electrokinetic dewatering and consolidation of metal-mine tailings. Tailings were subjected to DC potential until dewatering ceased. Measurement of time, water removal, resistivity and power consumption were recorded. Equipment and procedures were developed for a particular mine. Indications are that the method is highly effective in consolidating that material.

________. Laboratory Experiments in Electrokinetic Densification of Mill Tailings-2. Application to Various Types and Classifications of Tailings. U.S. Bureau of Mines, RI 7900. 1974. 36 pp.

This report describes Bureau of Mines laboratory test results in electrokinetic dewatering and consolidation of metal-mine tailings from five mines in the Coer d'Alene, Idaho district. Results were best with well-mixed unclassified tailings and indicated that these mill tailings can be effectively treated using electrokinetics.

________. Limited Field Tests in Electrokinetic Densification of Mill Tailings. U.S. Bureau of Mines, RI 8034. 1975. 47 pp.

Extensive Bureau of Mines laboratory testing has shown that electrokinetic densification is effective in dewatering and densifying metal-mine mill tailings. Eighteen cubic-yard concrete model stopes, 18 feet long by 6 feet deep by 56 inches wide, were filled with tailings slurry from a metal mine in the Coer d'Alene, Idaho district. A strong dense fill was obtained with power consumption of 25 to 30 kw-hr/yd^3 of densified fill. The 1975 power cost in the Coer d'Alene district is 10 to 12 cents/yd^3.

________. Electrokinetic Densification of Hydraulic Backfill-A Field Test. U.S. Bureau of Mines, RI 8075. 1975. 20 pp.

Hydraulic backfill of siliceous mill tailings was successfully dewatered and consolidated by electrokinetics in a 2000-foot level stope at the Star Mine in Burke, Idaho. The material, a mixture of sands and slimes, was densified with about 3 hours of treatment. This test suggests ways of handling troublesome slime problems in many mines.

________. Dewatering and Densification of Coal Waste by Direct Current-Laboratory Tests. U.S. Bureau of Mines, RI 8197. 1976. 67 pp.

Laboratory tests using DC to dewater and densify fine-grained coal sludge were made to alleviate disposal problems. Solids in the slurry were very fine, 65 percent of less than 0.1 mm in diameter. One test using soupy slurry (55 percent dry-weight moisture content) was converted into a firm, dense material with 20 percent dryweight moisture content. Results were achieved in 3 hours at current density of 3.7 amp/ft^2 and a power expenditure of 35 kwh/yd^3. The treated material had a heating value of 10,400 btu/lb.

________. "Using Slimes for Backfill in Deep Mines." Mining Congress Journal. pp. 22-26. April, 1976.

Underground mine operators need fill material and, to meet environmental standards, a place to stow slow-settling mill wastes (slimes). A safe, effective, and economical method of utilizing

such slimes in stope backfill could help solve these needs. Recent work on electrokinetic densification suggests this may be the answer.

State of Tennessee, Department of Labor-Division of Mines. *Laws and Regulations Governing Mines and Mining (Title 58)*. 1976. 215 pp.

Copies of the laws governing all mining, including coal, in the state are provided, in addition to a 1976 cumulative supplement covering the same subjects.

Stevens, A.L. *Oil Shale Programs-First Quarterly Report-January 1976 through March 1976*. Sandia Laboratories, 76-0259. 1976. 39 pp.

This is an example of a small part of the kind of research work being done attempting to find systems, instruments, and methods to measure or visualize the controlling physical variables affecting in situ oil shale processing.

Stockdale, Paris B. and Harry J. Klepser. *The Chattanooga Shale of Tennessee as a Source of Uranium. Final Report*. University of Tennessee, ORO-205. 1959. 223 pp.

The major objective of the study was to obtain a thorough geologic picture of the Chattanooga Shale in the selected area, Eastern and Northern Highland Rim, a small portion of adjoining Kentucky, and scattered outliers in the Nashville Basin. Emphasis was placed upon stratigraphic relationships and associated problems.

Swanson, Vernon E. "Uranium in Marine Black Shales of the United States." Paper presented at International Conference on the Peaceful Uses of Atomic Energy. June, 1955. 10 pp.

Since 1945 black shales have been regarded as possible low grade resources of uranium and numerous black shale units in the U.S. have been tested for their uranium content. A few contain on the order of 0.007 percent uranium. Possibilities for finding shales of better grade have not been exhausted. No uranium has been produced from shales in the U.S. because of the relatively high grade of other type deposits.

________. Oil Yield and Uranium Content of Black Shales. U. S. Geological Survey, Professional Paper 356 A. 1960. 44 pp.

Uraniferous shales containing both uranium and oil have been considered as a potential source of both. Oil yield and uranium determinations on more than 500 samples of these shales are recorded in this report. These shales cover extensive areas of mid-continent and eastern U.S.

________. Geology and Geochemistry of Uranium in Marine Black Shales-A Review. U.S. Geological Survey, Professional Paper 356 C. 1961. 111 pp.

From 1944 through 1947 more than 200 formations in the U.S. containing black shale units were examined as possible sources of uranium. Only the Chattanooga and the phosphatic black shales of Pennsylvania age in Kansas-Oklahoma were found to have a relatively high uranium content, generally between 0.005 and 0.010 percent. The modes of concentration of uranium presented here are based on: (a) geologic studies of uraniferous marine black shales, as the Chattanooga; (b) sedimentologic studies of modern uranium bearing black muds of the Norwegian fjords and the Baltic Sea; (c) hydrologic studies of the waters in which these muds are deposited, and (d) laboratory experiments in uranium precipitation related to conditions observed in the first three categories. The immediate uranium source is seawater. The paper describes variables in creating its deposition in the black shales.

Swanson, V.E. and T.M. Kehn. Results of the 1952-1953 Sampling of Chattanooga Shale in Tennessee and Adjacent States. U.S. Geological Survey, Trace Elements Investigations Report 366. 1955. 98 pp.

Uranium analysis of 874 samples collected in 1952 and 1953 from 55 outcrops and 14 drill holes in Chattanooga Shale in central Tennessee, southern Kentucky, northern Alabama, and northwest Georgia tend to

support the conclusion regarding uranium distribution presented in Swanson [1961]. No area is believed to exist where average uranium content of the Chattanooga is appreciably higher than has been reported. Variabilities in thickness and uranium content are discussed.

Tarman, P.B., H.L. Feldkirchner, S.A. Weil and J. Janka. Hydroretorting Process for Eastern Shale. Society of Petroleum Engineers 6628. 1977. 8 pp.

A new process has been developed for converting eastern shales to SNG and/or syncrude. Conventional retorting can extract only about 33 percent of the organic carbon content of these shales whereas the new hydroretorting process can extract 85 to 90 percent. Hydroretorting is based on experimental results obtained in laboratory and bench scale tests. Diagrams of the laboratory thermobalance and other equipment are shown. During hydroretorting hydrogen partial pressures up to 500 psig at low shale heat-up rates made possible high organic carbon recoveries.

Tourtelot, Elizabeth B. Selected Annotated Bibliography of Minor-Element Content of Marine Black Shales and Related Sedimentary Rocks-1930-65. U.S. Geological Survey, Bulletin 1293. 1970. 118 pp.

Included are abstracts of about 375 selected articles published during 1930-65 pertaining to worldwide occurrences of black shale. However, readers interested specifically in uranium distribution in black shales of the U.S. are referred to an annotated bibliography compiled by Fix (1958). References to uranium after 1956 (cut-off date for the Fix compilation) are included herein.

Trepp, Donald W. "Mining of Oil Shale Commercially by the Room and Pillar Method." Presented at Society of Mining Engineers Fall Meeting, Salt Lake City, Utah. September 10-12, 1975. 14 pp.

Colony Development operation is a joint venture of Oil Shale Corporation, Ashland Oil, Shell Oil, and Atlantic Richfield,

operator. Objective is to develop a commercial oil shale plant. Colony announced postponement in 1974 of imminent plant construction but will continue planning. Paper describes planned operation when constructed.

Uranium Ore Processing. Panel Proceedings Series. International Atomic Energy Agency, Washington, D.C. November 24-26, 1975. 238 pp.

This conference on uranium ore processing was attended by 49 participants from 17 countries, and one international organization. Eighteen papers were presented and covered the following topics: future demand and need to increase milling capacity; milling techniques which have not reached full application; process problems and developments for new ore occurrences; processing low grade resources; uranium as a by-product and by-products from uranium areas; in situ leaching; uranium from seawater. A panel of participants summarized the conclusions of the meeting along with recommendations for future action.

U.S. Atomic Energy Commission. Nuclear Power Growth-1947-2000. Washington 1139. 1974. 74 pp.

This forecast of the growth of nuclear power in the U.S. and the rest of the world represents a current evaluation of domestic and foreign trends in the growth of nuclear power, the future capability of foreign nations to supply uranium enrichment services to reactor operators, the timing and application of plutonium recycle technology, and the timing and rate of introduction of the fast breeder reactor.

U.S. Bureau of Mines. Retorting Chattanooga, Tennessee Oil Shale Entrained Solids Retort Run 26-1400°F. Intra-Bureau Report OSRD-68. Oil Research Branch. 1953. 14 pp.

Report presents data from the second experiment (Retort Run 26) in which Chattanooga Oil Shale was retorted in the entrained solids retort at 1400° F. Spent shales from this experiment were shipped to Professor M.D. Hassialis (Mineral Benefication Laboratory-Columbia University) who reported on the analysis and characterization of the various oils.

________. The Florida Phosphate Slimes Problem-A Review and Bibliography. U.S. Bureau of Mines, IC 8668. 1975. 41 pp.

The Florida phosphates industry produces about 30 million tons per year of phosphate rock for fertilizers. Associated with the fertilizer as a waste are the same amounts of clay slimes. These clays retain a high percentage of water over many years and constitute an environmental damage threat. This report discusses the problem, reviews past research, and makes recommendations for future work. A large bibliography is included.

________. Field Compaction Tests-Research and Development Program and the Disposal of Retorted Oil Shale-Paraho Oil Shale Project. Phase V Interim report. 1976a. 86 pp.

This report is one of a series studying the physical characteristics of oil shale retorted by the Paraho process at Anvil Points, Colorado. The main objective of this Phase V program was to secure information on the compaction characteristics of the retorted shale when densified in the field by various types of commercial compacting equipment. Effects of number of equipment passes, layer thickness, and adding moisture were studied and are reported.

________. Disposal of Retorted Oil Shale from the Paraho Oil Shale Project-Final Report. 1976b. 471 pp.

As part of a Paraho retort demonstration project at Anvil Points, Colorado, laboratory and field tests were done to determine the physical and chemical properties of the retorted shale to develop eventual full-scale disposal plans. Compacted material exhibits shear strength similar to silty gravel soils, gaining strength over time through cementing action, but dependent on retorting variables. Total dissolved solids are 1.4 percent by weight. Water requirements for retorting and disposal will be small. High strength of the retorted shale will allow high cross-valley dams on steep slopes.

U.S. Department of Energy. 1977 NURE Uranium Geology Symposium, December 7-8, 1977, U.S. Department of Energy GJBX-12(78) 248 p.

This 1977 Geology Symposium is an effort by Bendix on behalf of the DOE to present topical geology project results and status reports on current criteria development studies that will be key ingredients in the upcoming NURE favorability studies and uranium resource assessment.

The symposium has been organized by host rock type with the initial two papers presenting ore deposit classifications intended to facilitate resource assessment tasks. More and more geological information is being squeezed from LANDSAT data, and there are some new geology dedicated remote sensing systems in the planning stage. As a result and to supplement the host rock presentations a short session on remote sensing has been included.

U.S. Energy Resource and Development Administration. Oil Shale-FY 1977. Environmental Development Plan. 1977. 49 pp.

This plan identifies and examines the environmental health, safety, and socioeconomic issues concerning the development of the ERDA Oil Shale Program, and the requirements for resolving these issues, including the action plan for evaluation and mitigation of environmental impacts.

U.S. Environmental Effects Laboratory, U.S. Army Corps of Engineers. Laboratory Study of Aeration as a Feasible Technique for Dewatering Fine-grained Dredged Material. Final Report. Environmental Engineering Consultants, Inc., Stillwater, Oklahoma. 1976. 71 pp.

Improvement of facilities for dewatering fine-grained dredged material is the topic of this publication. Rapidly escalating requirements for land in which to confine dredged material, often in urban areas, dictate priority to such research. A method to increase the rate of water removal from fine-grained dredged material is described and evaluated.

U.S. Geological Survey. "Preliminary Reconnaissance for Uranium in Alabama, Georgia, Mississippi, Tennessee, Virginia, and West Virginia, 1950 to 1955." Atomic Energy Commission, RME-4104-Geology and Minerology (TID-4,500).

A detailed listing of each sample site as to important aspects such as location, kind of sample, name of property owner, sample size, etc.

Volkwein, J.C. and P.F. Flink. Respirable Dust Survey of an Underground Oil Shale Mine and Associated Milling Facility. U.S. Bureau of Mines, IC 8728. 1977. 23 pp.

The Bureau of Mines conducted a field study of respirable dust concentrations occurring underground and on surface at an oil shale mine. Major dust sources and mineralogic content of the dust was determined. Alpha-quartz content of the mill dust was almost 4 times higher than the mine dust. The best precision to date was observed with personal dust samplers operated in the field.

Walsh, John. "West Virginia: Strip Mining Issue in Moore-Rockefeller Race." Science 178:484-486. 1972.

This report outlines some of the political influences affecting strip mining of coal in W. Virginia, largest producer of coal of all the states; 109 million tons in 1975, 19 percent of which was strip mined.

Weeks, J.B. "Groundwater Problems With Oil Shale Mining in the Piceance Basin." Water Spectrum 8(1):8-14. 1976.

Large quantities of oil-containing Green River Formation Oil Shales are found in the Colorado Piceance Basin and are under study for the production of oil. Major problems regarding the effects of mining the shales on groundwater are discussed. Aquifer systems are described.

Weston, Roy F., Inc. Concept Evaluation Report, Taconite Tailings Disposal. Environmental Protection Agency. October, 1971. 157 pp.

Conceptual methods were developed for treating and disposing of taconite wastes and to make an independent evaluation of feasible wastewater treatment and disposal alternatives. The following are covered: major issues from previous studies of tailings discharges to Lake Superior; technical review of previous proposals for treatment and disposal; discussion of the current process investigation and tailings reuse; concept design of various alternatives; the economic and financial effect on Reserve Mining and Minnesota by the various proposals.

World Mining. Florida P_2O_5 Tailing Disposal Looks Good; Three Sand Clay Mining Systems. November, 1977. 3 pp.

Since mining of phosphate in central Florida began, one of the most troublesome problems has been the settling of the great quantities of waste clay slimes associated with the phosphate particles. A new system devised by an industry-supported research group finds a way of confining the clay slurry below ground level and of dewatering the clay more efficiently.

________. Belt Conveying, Not Pumping, Used by Brewster P_2O_5 for Florida Matrix. January, 1978. 5 pp.

Lonesome Phosphate Mine of Brewster Phosphates is located in the SE part of Hillsborough County, part of the Florida Land Pebble Phosphate District. A new mine, it is designed with innovative techniques to belt convey deslimed matrix from the mine to the processing plant and use the same belt to return flotation tailings back to the mine for placement in the reclaiming area.

Wright, F.D. and P.B. Bucky. Determination of Room and Pillar Dimensions for the Oil Shale Mine at Rifle, Colorado. American Institute of Mining and Metallurgical Engineers, Technical Publications No. 2489. 1948. 8 pp.

This report gives some of the earliest results obtained in research on mining problems, roof support, pillar size and other factors related to oil shale mining at Anvil Points near Rifle, Colorado. Physical characteristics were obtained by testing rock specimens in a centrifuge.

Zambas, P.G., G.R. Haworth, F.W. Brakebusch, and J.B. Sellers. "Large-Scale Experimentation in Oil Shale." Society of Mining Engineers Transactions 252:283-289. 1972.

The program of large-scale mining experimentation carried on in Stage II of the Anvil Points Oil Shale Research Program, Rifle, Colorado is reported. Results of various types of mining, roof control, transportation, and ventilation procedures are appraised.