GJO-108(79)

CONF-7910129--

URANIUM INDUSTRY SEMINAR

PROCEEDINGS

October 16 & 17, 1979
Grand Junction, Colorado

U.S. DEPARTMENT OF ENERGY
Assistant Secretary for Resource Applications
Grand Junction, Colorado

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GJO-108(79)

U.S. Department of Energy
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Contents

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INTRODUCTION

The ninth annual Uranium Industry Seminar, sponsored by the U.S. Department of Energy's (DOE) Grand Junction Office, was held in Grand Junction, Colorado, on October 16 and 17, 1979. There were 833 registered attendees as compared to 829 attending the previous year. The attendees were drawn largely from uranium and other energy resource companies, electric utility firms, energy consultants and service companies, and governmental agencies. In addition, there were representatives present from Indian tribes, universities, the media, DOE Laboratories, and foreign countries and organizations.

There were 16 papers presented at the Seminar by speakers from the Department of Energy, U.S. Geological Survey, and Bendix Field Engineering Corporation which is the on-site prime contractor for DOE's Grand Junction Office. The topics of the papers dealt with uranium policies, exploration, resources, supply, enrichment, and market conditions. There also were papers describing the National Uranium Resource Evaluation program and international activities.

The text and illustrations of each paper are included in this report. A list of attendees is contained in the appendix.

URANIUM ENRICHMENT POLICIES

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Office of Uranium Resources and Enrichment
U.S. Department of Energy
Washington, D.C.

October 1979

Presented by Rhonnie H. Smith

INTRODUCTION

I am very pleased to have the opportunity to participate once again in this seminar which continues to receive national attention.

All of us involved with any facet of nuclear energy problems—whether in industry, government, or the general public—must operate, plan, and make decisions in an environment of considerable, if not extreme, uncertainty, and this situation is not likely to change very soon. The uranium industry, of course, is no exception to this. It constantly faces critical decisions in such areas as exploration investment, opening of new production facilities, changing mine-operating conditions, and uranium sales transactions. At the same time, there is the definite problem of predicting future uranium markets primarily due to uncertainties in projecting nuclear power growth, and to a lesser extent, to other considerations such as reprocessing and timing of introduction of alternative nuclear technologies.

The U.S. Department of Energy (DOE) policies for operating the U.S. uranium enrichment facilities also affect the timing and quantity of uranium demand. The health and viability of the uranium industry are important considerations in planning our enrichment operations. In this paper and the following one, we would like to bring you up-to-date on our enrichment activities.

ENRICHMENT PROGRAM GOALS

The goals of the DOE uranium enrichment program may be briefly stated as shown in figure 1.

In order to achieve these goals, the DOE has several efforts underway as described in figure 2.

- To meet domestic and non-U.S. requirements for uranium enrichment services in the most economical, reliable, safe and environmentally acceptable manner
- To supply uranium enrichment services to the U.S. market and be a major supplier to the non-U.S. market

FIGURE 1. *Enrichment program goals*

- Monitor nuclear power growth trends
- Expand uranium enrichment capacity as appropriate
- Pursue an aggressive marketing program

FIGURE 2. *DOE efforts in support of uranium enrichment goals*

NUCLEAR POWER GROWTH

At last year's seminar, I presented the estimate of domestic and non-U.S. nuclear power growth on which operational planning of the enrichment complex was based. At that time, we had planned on DOE enrichment capacity supporting 115 gigawatts (GWe) of domestic nuclear power capacity and 65 GWe of non-U.S. nuclear power capacity that would be on-line by the end of 1985. Similarly, we planned that 185 GWe of domestic nuclear power and 100 GWe of DOE-supplied non-U.S. nuclear power would be on-line by the end of 1990. Based on that projection, which represented a significant reduction in the demand for enrichment services from prior projections, actions were taken to avoid unneccessary early inventory buildup and near-term budget expenditures. DOE negotiated with its power suppliers to reduce power in the Fiscal Year (FY) 1979-1981 period and also rescheduled the Portsmouth Gas Centrifuge Enrichment Plant, such that only 2.2 million separative work unit (SWU) capacity would be on-line by 1988 as compared to the 8.8 million SWU capacity previously scheduled to be available at that time.

Since last year, it appears that the trends are toward further retardation in the rate of growth of nuclear power. A little later in this seminar, R. Gene Clark will present recent DOE Energy Information Administration (EIA) forecasts of installed nuclear power which will illustrate this. However, nuclear power must remain an essential element of our energy supply for many years. The nuclear option is not one we can afford to discard.

As uncertain as the future normally is for forecasters, events in the last year have created a future that is even more difficult to forecast. Nonetheless, we are now in the process of trying to evaluate the likely effect of these events and to develop the proper uranium enrichment operating strategies. Pending modifications necessitated by this changing environment, I will now describe DOE current plans regarding expansion of our uranium enrichment facilities.

EXPANSION OF DOE URANIUM ENRICHMENT CAPACITY

In recognition of the growing need for enriched uranium fuel, the United States Government has taken actions to assure that sufficient uranium enrichment production capacity will be available. As shown in figure 3, DOE is currently implementing major programs to:

- Increase the capacity of the existing gaseous diffusion complex via the Cascade Improvement Program (CIP) and the Cascade Uprating Program (CUP), and

- Construct a Gas Centrifuge Enrichment Plant (GCEP).

Significant advances have been realized in each of these expansion efforts. The CIP program provides a large increase in separative capacity by improving the efficiency of the gaseous diffusion process equipment. This program provides an enrichment capacity increase of about 32 percent with no increase in power requirements at the existing three plants. The CUP expands gaseous diffusion plant enrichment capacity by increasing the throughput of the three plants. This is achieved by increasing the power-handling capability of the three plants from 6,065 to 7,380 megawatts. The combined three-plant separative work capacity will increase by an additional 20 percent as a result of CUP. Both CIP and CUP are essentially on schedule and within costs. They will be completed in 1982 at a capital cost of about $1.5 billion. CIP and CUP will increase enrichment capacity from 17.2 to 27.3 million SWU's per year as shown in table 1. The 1982 date represents a slight delay from our original planning which expected a completion date of September 1981. However, due to a prolonged work stoppage at the Portsmouth plant, which began in early May of this year and is still in progress, the September 1981 completion date will not be met at that site. Incorporation of these two programs into our enrichment complex is economical and of great benefit to our customers. The incremental SWU cost of the additional production associated with the CIP and CUP programs is $22 and $60 (based on current dollars), respectively.

- CIP & CUP
  - —Will expand existing gaseous diffusion capacity by 60%
  - —Will be completed within the cost estimate of $1.5 billion
  - —Will be completed in 1982
- GCEP
  - —Will expand enrichment capacity by an additional 32%
  - —Will assure customers that their tails assay will not exceed 0.25% ^{235}U
  - —Allows DOE to sign new enrichment services contracts

FIGURE 3. *Programs to expand U.S. enrichment capacity*

For nearly 20 years, gas centrifuge technology for isotope separation has been under intensive development in the United States. As a result of progress made in these development efforts, the gas centrifuge process is now ready for use in a production-size uranium enrichment plant to be built at Portsmouth, Ohio. This process has several attractaive features relative to gaseous diffusion. It requires only about 5 percent of the electrical power needed for a gaseous diffusion plant of similar capacity. Also, it can be bult in modular units well within the time needed to construct a nuclear power plant. This modular feature enables the plant to be built in a manner to more closely match supply and demand.

TABLE 1. *Expansion of gaseous diffusion capacity*

	Completion Date	Enrichment Capacity 10^6 SWU/yr
Unimproved gaseous diffusion plants	Mid 1950s	17.2
CIP	1982	5.5
CUP	1982	4.6
Total gaseous diffusion	1982	27.3

The new gas centrifuge enrichment plant project is progressing on schedule. There are presently nine Architect Engineering firms on board. Four construction contracts have been completed, and eleven others are underway including the site rough-grading which is 20 percent complete. Eighteen off-site and demonstration facilities are being designed or constructed. A total of 2,500 people are now directly employed in design and construction of the plant.

In addition, major procurement contracts have been placed for centrifuge machines, process building structural steel, power transformers, and some of the classified raw materials. One of the centrifuge machine manufacturers has broken ground for a new production plant at Oak Ridge, Tenn. So far, eight hundred million dollars has been appropriated for the project by Congress and one hundred eighty-five million dollars has been costed.

The Portsmouth GCEP will eventually provide approximately 8.8 million SWU's per year of additional uranium enrichment capacity. This plant, being built adjacent to the existing Portsmouth Gaseous Diffusion Plant, will operate in an integrated mode with the three existing gaseous diffusion plants. Figure 4 shows an artist's conception of the Portsmouth GCEP. The initital section of the first GCEP process building, called the early train and currently scheduled to be on-line in 1984, will provide the first operation of commercially mass-produced centrifuges. Preceding the early train will be the operation of the centrifuge plant demonstration facility in 1982 which will provide operating experience of a unit cascade with commercially produced centrifuges. Production of separative work from the GCEP is scheduled to begin in 1987, with a capacity of 2.2 million SWU's per year on-line in 1988. Additional production capacity will be added in 1.1 million SWU increments as demand for enrichment services indicates the need. For planning purposes full production of 8.8 million SWU's per year is currently planned for 1993. The total estimated cost for the plant is $5.1 billion in Fiscal Year 1980 dollars. As shown in table 2, total U.S. enrichment capacity in the United States will be 36.1 million SWU's when GCEP is completed.

The commitment by President Carter and his Administration to build the GCEP has allowed DOE

TABLE 2. *Expansion of uranium enrichment capacity*

	Completion Date	Enrichment Capacity 10^6 SWU/yr
Gaseous diffusion with CIP & CUP	1982	27.3
GCEP buildings 1 & 2	1988	2.2
GCEP buildings 3 thru 8	1993	6.6
Total authorized capacity	1993	36.1

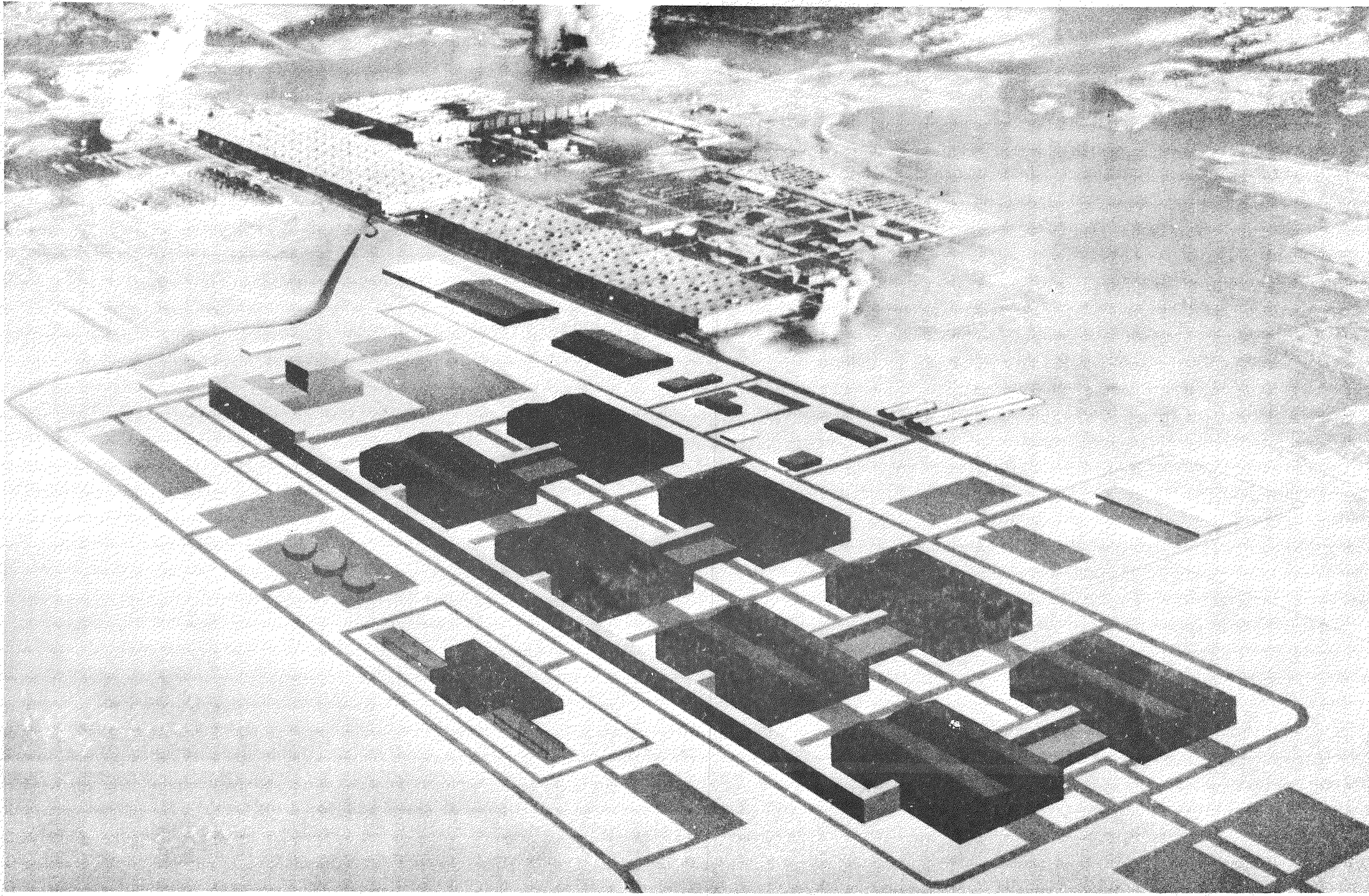

FIGURE 4. *Gas centrifuge enrichment plant, Portsmouth, Ohio*

to reopen the order book and assure existing and new uranium enrichment customers that it is expecting to provide such services at a transaction tails assay no greater than 0.25 percent ^{235}U, a level that conserves the supply of natural uranium.

MARKETING

DOE has initiated a customer-oriented marketing program to ensure more sensitivity to customers' overall enrichment needs and problems and to communicate more effectively to the non-U.S. utilities the benefits of contracting with DOE for enrichment services. Over the last several years, the enrichment business has become very competitive. The United States is no longer the only commercial international supplier. Some countries, e.g. Japan, Brazil, and South Africa, have programs to supplement their domestic needs, while others, e.g. members of Eurodif and Urenco, are providing services to domestic and foreign markets. During much of this same period of growth in enrichment supply, the enrichment demand worldwide has shrunk. The U.S. market is expected to be very small for the next year or two. Over the near term, it appears to us that the major markets will be in Asia, the Middle East, and Latin America.

DOE is both willing and able to supply enrichment requirements to fuel nuclear reactors on as an economical and reliable basis as world demand dictates. President Carter has stated that "The United States intends to remain a dependable supplier of uranium enrichment services in order to provide adequate and timely supply of nuclear fuels for domestic and foreign needs." Consequently, DOE, and more specifically the Office of Uranium Resources and Enrichment (OURE), is taking steps to implement this commitment in a manner that keeps our customers' total needs continually in mind. Since May 1978, when DOE reopened the enrichment services order books, we have been in the position of being able to accept new business. In order to make our services more attractive, a new Adjustable Fixed Commitment (AFC) contract was offered in July 1978. The AFC contract terms and conditions reflect our responsiveness to the changing needs of the world nuclear power market and our ability to provide increased contractual flexibility. Attractive new features of this contract are described in figure 5.

- Price and tails assay guarantees
- Variable tails assay option
- Greater quantity and time flexibility
- Flexibility in scheduling the initial delivery period
- A five-year rolling firm commitment period
- Long-term contract (10 to 30 years at customer option)
- Ability to do fractional contracting
- Small initial advance payment
- Right to assign or sell separative work

FIGURE 5. *Features of the adjustable fixed commitment contract*

This contract is available to new customers and to those holding existing contracts. We have structured the AFC contract to be highly competitive with the enrichment service arrangements of the other world suppliers taking many of our customers' comments on the initial draft into consideration for the final contract. DOE will continue to improve its contracts so that they reflect customer needs and current market conditions. For example, we have instituted a very recent contract improvement which reduces the financial liability to the customer if legislation is passed, after a contract is signed, which imposes more stringent fuel export requirements. Also DOE will soon notify all AFC contract customers that they have the option of deferring a part instead of the whole amount of enrichment services from one year into another. Any deferral, of course, will be subject to deferral charges.

To date, response to the AFC contract has been quite favorable. Most of our existing customers have elected to convert their Long-Term Fixed Commitment (LTFC) contracts to AFC contacts. The status of conversions as of September 30, 1979, is shown in table 3. As can be seen, about 80 percent of our existing LTFC customers have converted to an AFC contract. In addition to the conversions, we have signed three new AFC contracts—one each with Egypt, Japan, and the Euratom Supply Agency. We also anticipate that additional new AFC contracts will be signed in the relatively near future.

I would next like to discuss several topics which are of direct interest to the uranium industry—specifically, the variable tails assay option, the current status of DOE inventories of natural and

TABLE 3. *Status of AFC contract conversions as of 9/30/79*

	U.S.	Non-U.S.	Total
Eligible	125	90	215
Converted	101	73	174
Not converted	24	17	41

enriched uranium, and our current tails assay expectations.

Variable Tails Assay Option (VTAO)

One feature of the AFC contract mentioned earlier is the availability of VTAO. This option permits our AFC customers to fine tune the amount of enriched uranium product they take by giving them flexibility to alter their natural uranium-feed delivery schedules. In June of this year, the terms and conditions for implementation of VTAO during FY 1981 were announced. The principal terms and conditions, as summarized in figure 6, include:

- Ability to choose a transaction tails assay at 0.01 percent intervals within the range of 0.16 to 0.30 weight percent ^{235}U, and

- A separative work penalty if the elected VTAO transaction tails assay is outside of the efficient operating range of the DOE enrichment complex. Efficiency loss factors for the various VTAO transaction tails assay are shown in table 4. Any customer exercising VTAO will be billed for the total separative work under contract, but the actual separative work delivered to him will be adjusted by the percentage efficiency loss applicable to his elected transaction tails assay.

For the above conditions, the typical AFC contract enrichment customer has the flexibility to reduce his enriched uranium product by as much as 11 percent or conversely to increase it by as much as 26 percent. These bounds would require the customer to deliver about 16 percent less natural uranium or conversely, to deliver about 51 percent more natural uranium. Only three customers elected to exercise the VTAO option in FY 1981, but more customers are likely to use this option in the future. However, we do not expect availability of this option to have a significant impact on the natural uranium industry.

- Ability to choose a transaction tails assay at 0.01% intervals within range of 0.16 to 0.30% ^{235}U

- SWU penalty will be assessed if VTAO tails assay outside of the efficient operating range of the enrichment complex (i.e., below 0.20% ^{235}U in FY 1981)

FIGURE 6. *Principal terms & conditions of VTAO in FY 1981*

DOE INVENTORIES OF NATURAL AND ENRICHED URANIUM

On July 1, 1979, DOE had inventories of:

- 8,400 metric tons of low-enriched uranium at an average assay of 2.94 percent ^{235}U, and

- 25,300 metric tons of DOE-owned and customer-owned natural uranium, equivalent to 32,900 short tons of U_3O_8.

It is DOE's plan that the enriched uranium inventories will be used:

- To meet requirements for enrichment services in those future years where the demand for separative work is greater than the supply of separative work, and
- To provide a working inventory of enriched uranium, needed in order that DOE may provide enrichment services on a timely basis, and cover possible U.S. participation in international nuclear fuel-assurance arrangements.

It is also intended that the natural uranium inventory, in conjunction with a small portion of DOE's enrichment capacity, will be used to supply U.S. Government requirements for enriched uranium. In addition, the natural uranium inventory

TABLE 4. *FY 1981 efficiency loss (%) vs. tails assay*

Transaction Tails Assay % ^{235}U	% Loss
0.16	0.60
0.17	0.48
0.18	0.37
0.19	0.29
0.20—0.30	none

may be used to overfeed the DOE enrichment plants as necessary to maintain appropriate DOE enriched uranium inventory levels. The bulk of the DOE natural uranium inventory will likely be disposed of via these mechanisms by the mid-1990s. It still remains DOE's policy not to dispose of any natural uranium through direct sales in the marketplace except if the quantity of desired enriched uranium is very small and undue effort would be needed to obtain the natural uranium for toll enrichment or if an emergency situation would exist and all reasonable attempts, without success, had been made to obtain natural uranium from commercial sources. R. H. Smith, in his paper, will discuss in greater detail the current status of the DOE enriched and natural uranium inventories. He will also provide you with more detail with respect to our plans concerning the amount that we will set aside for working and international fuel-assurance inventory needs.

TAILS ASSAY EXPECTATIONS

Figure 7 summarizes our current thinking with respect to the DOE transaction and operating tails assays. Based on review of many alternative operating and demand scenarios, it still appears likely that the current 0.20 percent ^{235}U reference transaction tails assay can be maintained until well into the 1990s. At that time, with the new contracts DOE expects to sign, the reference transaction tails assay may need to be increased to as high as 0.25 percent ^{235}U. It also is likely that the DOE enrichment plants can continue to operate at a tails assay of 0.20 percent ^{235}U until the late 1980s.

- Transaction tails assay
  - 0.20% ^{235}U until well into 1990 s
  - No greater than 0.25% ^{235}U
- Operating tails assay
  - Likely at 0.20% ^{235}U until late 1980s

FIGURE 7. *Tails assay expectations*

SUMMARY

In summary, the future rate of growth of nuclear power is presently highly uncertain and very difficult to predict. In the last year, significant progress has been made in U.S. efforts to expand its uranium enrichment capacity; future activities in this regard, of course, will be modified as necessary as nuclear power growth is better defined.

DOE in the last year has also carried on a customer-oriented uranium enrichment services marketing program designed to be more responsive to customer needs and current market conditions and highly competitive with other world suppliers. In this regard, customer response to DOE's new Adjustable Fixed Commitment (AFC) contract was very favorable with most of the existing Long-Term Fixed Commitment (LTFC) customers electing to exercise their option to convert to an AFC contract. The VTAO feature of the AFC contract was also made available to customers for FY 1981. Only three customers elected to exercise this option in FY 1981, but more customers are likely to use it in the future. We do not expect, however, this option to have any significant impact on the natural uranium industry.

DOE inventories of natural uranium still remain high. However, DOE still plans to dispose of this material by using it for government requirements and plant operations. It still remains DOE's policy not to dispose of this material through direct sales in the market place except for very small quantities or if an emergency would exist and all reasonable attempts, without success, had been made to obtain natural uranium from commercial sources.

Finally, with respect to DOE's plans regarding future transaction tails assays, it appears likely that the current 0.20 percent ^{235}U reference transaction tails assay will be maintained until well into the 1990s at which time it may be increased to as high as 0.25 percent ^{235}U.

URANIUM ENRICHMENT PLANS

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Office of Uranium Resources & Enrichment
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Washington, D.C.

October 1979

INTRODUCTION

It has been pointed out in the previous paper that forecasting is an inexact art. The energy sector of the United States is undergoing a large amount of restructuring. The Administration and the Congress are emphasizing conservation, synfuels, new technologies, and domestic conventional fuels. Recent sharp increases in energy prices have tended to reduce usage, slowing economic and electricity growth. Thus, the demand for total and electrical energy, of which nuclear is a component, is in an unstable state relative to historical growths. For example, the national energy consumption growth has been projected to grow at a rate of 2.5 percent compared to the historic growth rate of over 3.5 percent. Similarly, electricity growth has been projected to decrease from about 7.5 percent historically to 4.1 percent over the remainder of the century. The role that nuclear energy will play is dependent on the outcome of many issues, e.g. waste management, the Kemeny Commission recommendations, utility financing, economic and electric growth, and realistic availablity of other economic and safe energy alternatives.

The future of nuclear power in other non-centrally planned countries is mixed; some are moving fast, some slow, and some not at all. I will describe some of these later in this paper.

As you know, the facilities for enriching uranium in this country are owned by and operated at the direction of the U.S. Government. The operational planning period for our enrichment production complex must cover 10–15 years, since the lead time for our customers' reactors is 10–12 years and the lead time for new enrichment capacity is 6–8 years. U.S. Department of Energy's (DOE) operational planning is based on our contract commitments and their potential changes and an assessment of the potential for new contracts. Our planning basis also includes determining our electric power requirements and timing of new enrichment capacity. Through combinations of these parameters together with operating and transacting tails assays, we develop an economically acceptable operating plan for our enrichment complex. As these parameters change, we must reevaluate the economic implication for the supply of enrichment services and perhaps modify our operating plan. Today, I will not be able to describe for you our new operating plan. Too many variables are uncertain. I do, however, want to discuss some of the uncertainties we are facing beginning with our customers contract status.

CONTRACT STATUS

For those who are new to DOE contracts, I will describe briefly the three contract types used by our customers (table 1). In addition, again for those who are new, I have included at the end of this report an appendix that contains two nomographs showing the relation between feed and separative work and product and tails assays.

"Requirements" contracts were offered by the Atomic Energy Commission (AEC) until December 1972. Since we had a very large enrichment capacity and few customers in the 1960s, advance notice for deliveries was not a problem. We agreed to supply the actual annual requirements of an individual reactor on at least a 180-day notice. The customer also provides a 5-year estimate of annual requirements and up to a 30-year estimate or for the life of the project, if less than 30 years. The contract ceiling is based on the 30-year estimate or total life requirements.

Long-Term Fixed Commitment contracts (LTFC) were issued from September 1973 through July 1974. During the last 3 years that "requirements" contracts were offered, it became evident that the capacity of our enrichment facilities would soon be

TABLE 1. *Types of contracts*

Requirement	Thru Dec 1972	• Few customers—large capacity • 180-day notice • Annual estimates • Ceiling on total SWU's over 30 years or less • Not transferable
Long-Term Fixed Commitment	Sept 1973–July 1974	• Increased rate of contracting • 10-year rolling firm requirements • Initial advance payment • Contract assignable
Adjustable Fixed Commitment	Since July 1979	• Increased flexibility, more competitive • Fractional contracts • Assignable or saleable • Variable tails option • 5 year rolling firm requirement • Adjustments during firm period

reached. The LTFC contracts provided a firm basis and advance revenues for expanding enrichment capacity. Under this contract form, customers provided a firm 10-year schedule of requirements each year and an initial down payment. The firm period applied to reactor units that were still in the planning or construction stage.

The Adjustable Fixed Commitment contract (AFC) that we now offer and the conversions from the LTFC to the AFC was described in the previous paper. The AFC was offered to customers in order to provide them with more flexibility in scheduling deliveries like the requirement contracts but maintain some degree of firm schedule deliveries like the LTFC. The AFC contract attempts to balance the risk of planning enrichment deliveries between DOE and the customer.

Table 2 shows a breakdown of our current contracts. Our toll enrichment contracts have decreased by nine reactors since the 1978 Uranium Industry Seminar. Two German utilities have given notice that they plan to terminate their contracts in the early 1980s. The losses of enrichment services to the nine reactors (all by termination) as shown in table 3 are:

1 "Requirements" Contract (Phillippsburg-2, Germany),
1 U.S. LTFC Contract (Allen's Creek),
6 Foreign LTFC Contracts (Germany, Spain, Iran, Sweden), and
1 Foreign Conditional LTFC Contract (Portugal).

Note that four of the terminations went to other enrichment suppliers in which they had interest in

TABLE 2. *DOE enrichment service contracts*

	Gigawatts			Units		
Type	**U.S.**	**Non-U.S.**	**Total**	**U.S.**	**Non-U.S.**	**Total**
Requirement	75	24	99	87	46	133
Adjustable fixed commitment	106	64	170	99	72	171
Long-term fixed commitment	19	16	35	20	18	38
TOTAL	200	104	304	206	136	342

TABLE 3. *Contract changes*

Country		Unit	Capacity—GWe
Germany	Terminated	Hamm*	1.100
	"	Biblis★◆	1.150
	"	Vahnum*	1.210
	"	Wuergassen★◆	0.640
	"	Philippsburg - 2★	0.860
Iran	"	Iran 1,2*	2.180
Spain	"	Valdecaballeros★	0.930
Sweden	"	Oskarshamn - 3†	0.900
U.S.	"	Allen's Creek*	1.150
Portugal	"	Portugal	0.760

**Projects canceled, others assigned to other users*
†Construction permits not granted
★Taken from other supplier
◆Termination effective 1982 (Biblis) and 1984 (Wuergassen)

national enrichment plants and that Sweden's total nuclear program is in question. Table 2 shows the contract assignments that have occurred since last year. Note that four LTFC contracts have been assigned to Korea. Two of these were from U.S. utilities, VEPCO and Delmarva, and two were from Israel. These assignments did not change the total number of reactors or total gigawatts (GWe). One other change which increased the megawatt (MWe) total but did not change the number of reactors under contract was the signing of a second AFC contract for the uprated Chugoku-4 unit in Japan.

Further changes in enrichment contracts now in force with DOE are anticipated since a number of reactors holding enrichment contracts have been postponed or cancelled. Potential assignments or terminations are likely from about a dozen U.S. reactors and perhaps nine foreign reactors.

TABLE 4. *Contract assignments*

From	To	Quantity
Vepco	Korea	Total
Delmarva	Korea	Total
Israel (two)	Korea	Total
Los Angeles W & P	Korea	1 year
	Taiwan	1 year
Thailand	Toledo Ed	2 years
	Taiwan	1 year
Pepco	Korea	1 year
	Toledo Ed	3 years
	Taiwan	1 year

OFFICE OF URANIUM RESOURCES AND ENRICHMENT (OURE) PLANNING PROJECTION

Briefly, I will review our early 1979 enrichment planning estimate of domestic and non-U.S. nuclear power on-line in 1985 which would obtain enrichment services from DOE. Our estimate, shown on table 5, was based on a reactor-by-reactor evaluation of the annual demand for enrichment services. At that time, we had forecasted 115 GWe of domestic nuclear power capacity and 65 GWe of non-U.S. nuclear power capacity, scheduled to be on-line in 1985, would be supported by DOE enrichment capacity.

The domestic estimates for 1990 included planned reactors which were not then under construction but which DOE judged would be needed and could be available to meet forecasted electrical power requirements. The non-U.S. projection for 1990 was based on similar consideration but included only those reactors expected to be supplied under DOE enrichment services contracts from our expanded facilities. The results of the projection indicated that 185 GWe of domestic nuclear power and 100 GWe of DOE-supplied non-U.S. nuclear power would be on-line by the end of 1990.

In February, these estimates of DOE-supplied enrichment services in 1985 and 1990 were considered reasonable and conservative for planning purposes. Accordingly, our Fiscal Year (FY) 1979 planning for enrichment services has been based on optimizing the DOE enrichment complex operating variables for supplying the needs of 180 GWe in 1985 and 285 GWe in 1990.

After 1990, the growth of nuclear power in the United States is less certain. The Energy Information Administration forecasted in April 1979 that by the end of the year 1995, the nuclear power capacity in the United States could range from 186 to 224 GWe. The sustaining capacity of the currently authorized DOE enrichment plants at 0.25 percent ^{235}U tails assay is about 325 GWe. For planning purposes, we have assumed that DOE's currently authorized capacity will sustain about 120 GWe derived from foreign sources and about 205 GWe from U.S. utilities. However, under our current marketing effort, we intend to do business with any country which cooperates with the U.S. effort to prevent proliferation of nuclear weapons and which agrees to International Atomic Energy Agency (IAEA) safeguards applicable to all nuclear activities within such a country.

PLANNING UNCERTAINTIES

Since early 1979, however, several events have occurred which have important implications with respect to the future of nuclear power in the United States and abroad:

- The Three Mile Island incident and the resultant uncertainty this incident placed on the future of nuclear power is still unfolding. The report from the Presidential Commission, created to review the safety of nuclear reactors and the future status of nuclear power in the United States, is imminent.

- The Fuel Use Act of 1978 is being implemented, and the President in his July message called for a 50-percent reduction in oil and elimination of gas, as fuels, to produce electricity by 1990.

- For the 52-week period ending August 4, 1979, the Edison Electric Institute reported a 5.1-percent increase in electrical energy distribution in the United States. A comparable number for the period ending September 2, 1978, was a 2.4-percent increase.

With respect to the non-U.S. market, several reactor projects have experienced cancellation, work suspension, and denial of operating licenses. Sweden will hold a referendum next spring to determine if it will have a nuclear program. Several units in West Germany and Austria have not received operating permits. Iran's program has been scuttled. Japan's program has been delayed several years. On the other hand, France, Spain, Taiwan, Korea, and Mexico's programs continue strong or are accelerating. Several countries this summer have reaffirmed their intent to generate 40 percent to 60 percent of their electricity from nuclear power by 1990 or 1995. The Nuclear Non-Proliferation Act and concerns over U.S. policies regarding reprocessing and breeder reactor deployment have created an atmosphere of uncertainty for non-U.S. customers relative to the United States as an assured supplier of enrichment services.

In view of this high degree of uncertainty in the nuclear market, we must still attempt to develop as reliable an enrichment demand forecast as possible in order that we may develop a production plan that will optimize the enrichment complex operating variables. We are now in the process of evaluating the likely effect of these types of events on

TABLE 5. *DOE projection of nuclear power reactors served by DOE enrichment plants*

In Gigawatts

	End of 1985			End of 1990		
	Domestic	Non-U.S.	Total	Domestic	Non-U.S.	Total
Upper limit of reactors under current DOE enrichment contracts	115	65	180	175	90	265
Possible additional reactors	0	0	0	5	5	10
More speculative additional reactors	0	0	0	5	5	10
	115	65	180	185	100	285

future enrichment demand and developing alternate operating strategies to meet varying demand scenarios. A new operating plan will be developed which balances stockpiles, tails assay, existing enrichment capacity, and availability of new enrichment capability over the 10- to 15-year planning period. In developing the operating plan, we will attempt to supply projected requirements for enrichment services at a transaction tails assay of 0.20 percent ^{235}U as long as possible but, in all cases, at no greater than 0.25 percent while maintaining DOE-owned inventories of low-enriched uranium at a 14 million separative work units (SWU) minimum stockpile level.

We plan to operate the enrichment complex such that the current 0.20 percent ^{235}U transaction tails assay will be maintained until after 1990, thereby allowing customers to obtain nuclear fuel close to the minimum projected cost of the fuel. Eventually, with the new contracts DOE expects to sign as a result of the DOE marketing efforts, the transaction tails assay may need to be increased to 0.25 percent ^{235}U.

STOCKPILES

On July 1, our low-enriched stockpile consisted of 35.2 million SWU's evaluated at 0.20 percent tails assay. This stockpile contains 8,400 metric tons of uranium (MTU) at an average assay of 2.94 percent ^{235}U. We expect that this low-enriched stockpile will be used to meet a portion of our customers' enrichment requirements for the next couple of years as we balance the stockpile level and current production with estimated future demand as shown in figure 1. After this inventory balancing period, we expect to again be in a preproduction mode of operation, such that the low-enriched inventory will increase through the mid-1980s and then decrease to a target-sustaining inventory level of 14 million SWU's of low-enriched uranium.

We consider the fourteen million SWU, shown in figure 3, to be a prudent minimum low-enriched inventory level. This target low-enriched uranium inventory level is comprised of:

1. Nine million SWU's as a working inventory (equivalent to three months of production from the DOE enrichment plants, when operating at full capacity after completion of the Gas Centrifuge Enrichment Plant [GCEP]). This inventory will serve as a buffer between the levelized daily production of enriched uranium and the wide variation in monthly shipments of finished product to enrichment

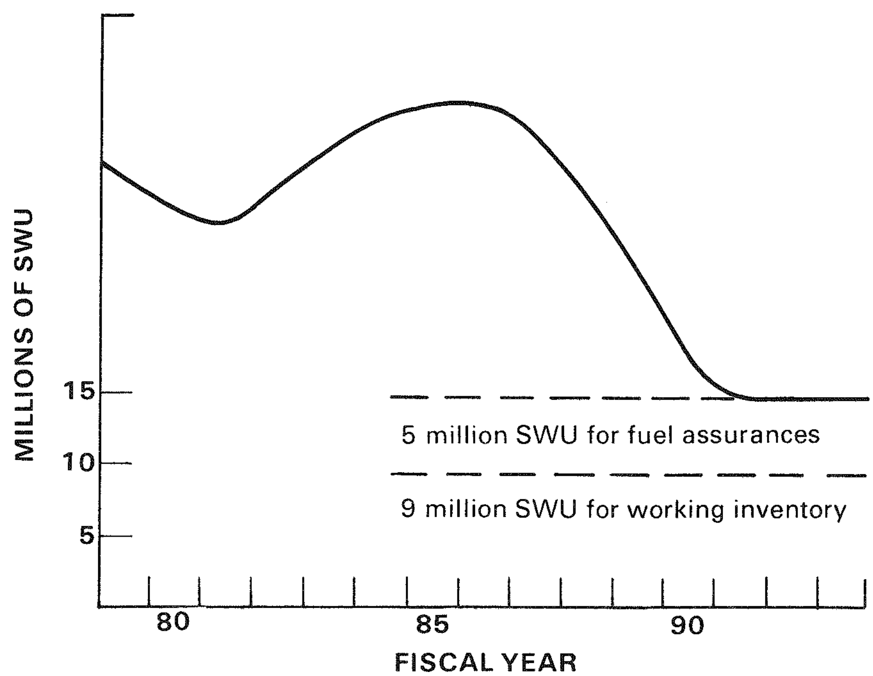


FIGURE 1. *Separative work contained in DOE low-enriched uranium inventory (evaluated at 0.25% ^{235}U tails)*

services customers (September 1979 shipments were more than three times the average monthly shipments). This working inventory provides assurance to customers that DOE will deliver on schedule.

2. Five million SWU's of the inventory are what President Carter has identified as a possible set-aside for international nuclear fuel assurance in response to Section 104(b) of the Nuclear Non-Proliferation Act of 1978.

The DOE holds a uranium stockpile comprised of material owned by enrichment services customers as well as our own material. The stockpile contains enriched, normal, and depleted uranium. Our policy on the use of this material was discussed in the previous paper. Table 6 shows the composition of this stockpile in terms of equivalent normal U_3O_8 as of October 1978 and July 1979. DOE, on occasions, uses its natural uranium feed for "split tails" operations, sales of very small quantities for research and test purposes, sales to satisfy emergency requirements and finally, sales of enriched uranium, including the natural feed component to meet certain older contractual obligations to five foreign reactors. The total of these sales of government-owned feed amount to about 300 short tons U_3O_8 per year, primarily for research, test purposes and five foreign power reactors.

Some of our depleted uranium (20,000 MTU containing the equivalent of about 5,000 short tons [ST] U_3O_8) is being sold to Italy. Since Italy has a large surplus of SWU's, they plan to upgrade this material and use it as feed. Their economics are very unique; therefore, we do not anticipate that this will become a general practice or that it will have any effect on the U.S. mining market. The tails offer no significant potential fuel or feed use until breeders or low-cost advanced isotope separation (AIS) are commercially available.

As noted in the previous paper, we plan to use the natural uranium inventory to supply U.S. Government requirements for enriched uranium and to maintain appropriate enriched uranium inventory levels. The operating plans that we develop to meet varying demand scenarios use the preponderance of the DOE-owned feed to meet these requirements.

SUMMARY

Much has changed since our last operating plan was prepared. Changes include Three Mile Island

TABLE 6. *Equivalent* normal uranium inventory short tons U_3O_8*

	10/78	7/79
Enriched-Normal	110,100	116,000
Low assay enriched	56,400	58,700
In process & high enriched	10,200	10,300
DOE normal	22,600	22,600
Japanese advance sale	15,400	14,100
Customer normal	5,500	10,300
Feed Liabilities	28,900	36,300
Early feed—domestic	4,200	3,900
—foreign	2,700	2,300
Usage agreement—domestic	1,600	1,600
—foreign	1,300	1,700
Japanese advance sale	9,900	11,400
Standard toll enriching	9,200	15,400
Net DOE Feed	81,200	79,700
Depleted uranium	19,100	18,900
0.30% ^{235}U	9,100	9,100
0.25% ^{235}U	9,800	9,800
0.20% ^{235}U	0	0

*Evaluated at 0.20% ^{235}U tails

and its ramifications, the Fuel Use Act, and the increased growth rate in electricity demand. There are many continuing issues and potential changes which will further impact nuclear fuel demand. We are currently in the process of developing and evaluating alternative operating strategies which will satisfy different demand forecasts.

These operating strategies will look at trade-offs between low-enriched stockpile levels, natural uranium stockpile levels, tails assays, and use of enrichment capacity and the scheduled availability of additional enrichment capability. These scenarios will be evaluated over the next few months as the FY 1981 Budget is compiled. The resulting operating plan will be announced early next year.

Years ago, Washington Irving wrote:

"There is certain relief in change
even though it be from bad to worse;
as I have found in traveling in a stage coach,
that it is often a comfort to shift one's
position and be bruised in a new place."

Nuclear power is a necessary part of the U.S. and world energy supply. We believe orders in the 1980s and installations in the 1990s will increase. Our plans include building the expandable GCEP and developing advance enrichment processes. As you can see, it is my belief that the nuclear industry will arrive—suffering through the bruises along the way.

APPENDIX

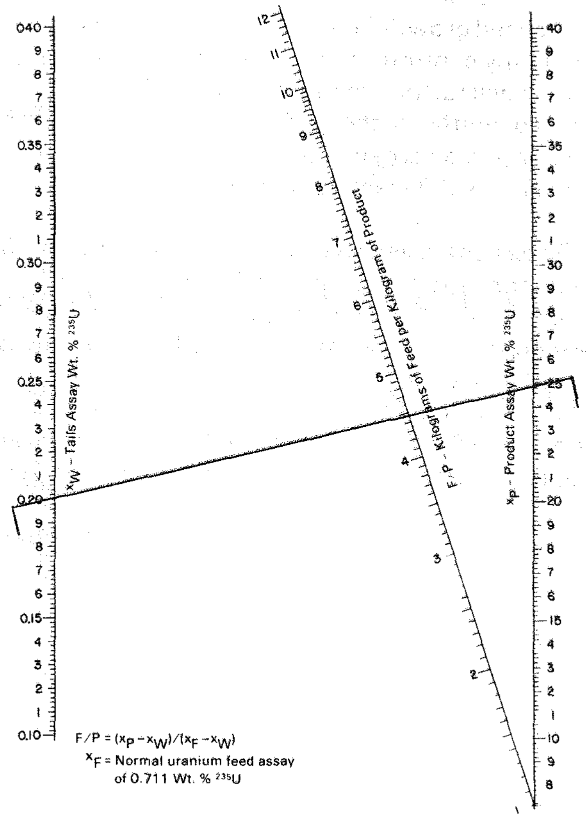
ILLUSTRATED USES OF NOMOGRAPHS

Note: All quantities of uranium are as kilograms of contained uranium in uranium hexafluoride. All assays are as weight percent ^{235}U.

NOMOGRAPH 1

Normal Uranium Feed Requirement

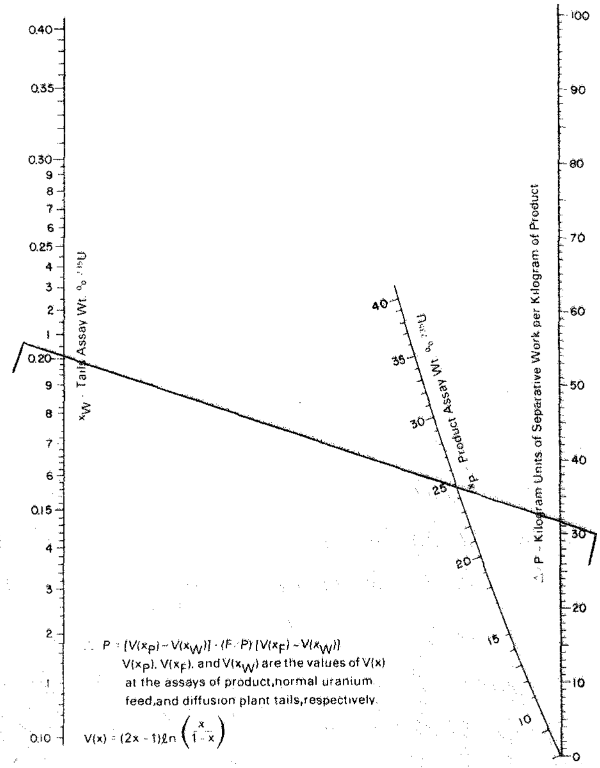
To find the amount of normal uranium feed required per kilogram of enriched uranium product, connect with a straightedge the tails assay of interest on the left line with the product assay of interest on the right line. The kilograms of normal uranium feed required per kilogram of enriched uranium product are found on the center oblique line at the point where it intersects the straightedge. To illustrate, a straightedge connecting a tails assay of 0.2% with a product assay of 2.5% intersects the feed requirement line at 4.50, the kilograms of normal feed required per kilogram of product under these conditions.

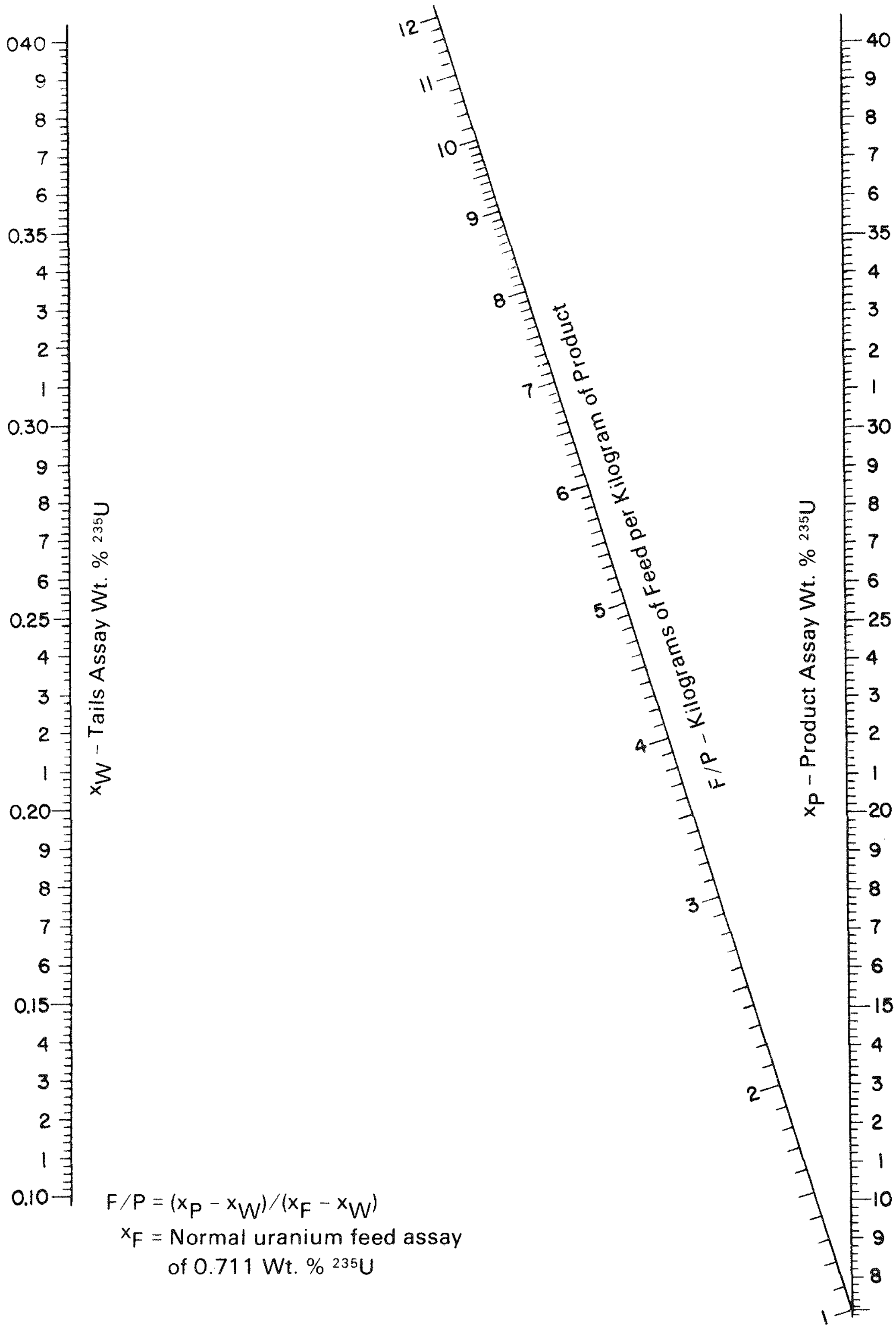


NOMOGRAPH 2

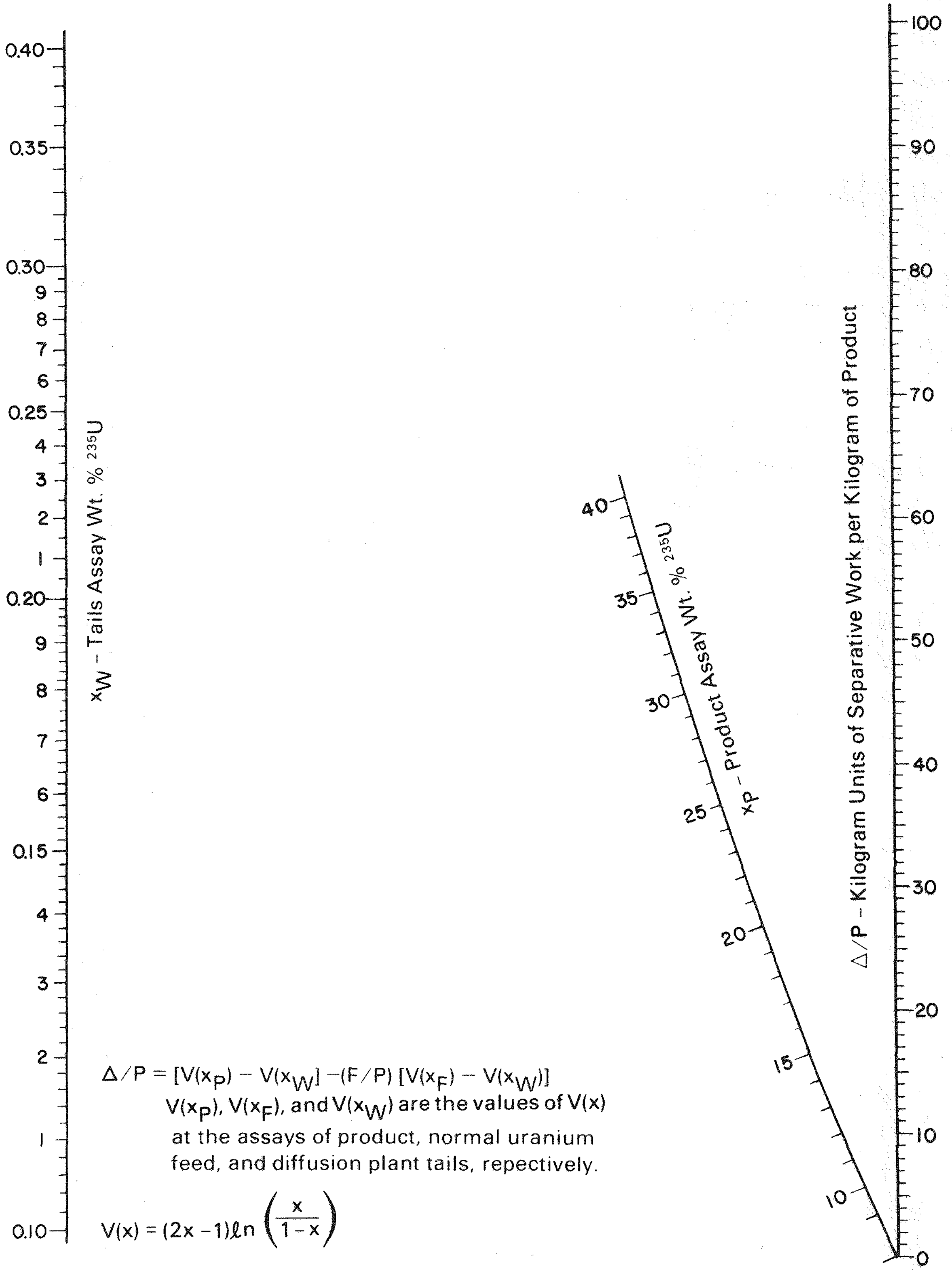
Separative Work Requirement

To find the amount of separative work required per kilogram of enriched uranium product when normal uranium feed is being enriched, connect with a straightedge the tails assay of interest on the leftline with the product assay of interest on the center oblique line. The kilogram units of separative work required per kilogram of enriched uranium product are found on the right line at the point where it intersects the extended straightedge. To illustrate, a straightedge connecting a tails assay of 0.2% with a product assay of 2.5% intersects the separative work requirement line at 3.23, the kilogram units of separative work required per kilogram of product under these conditions.





NOMOGRAPH 1. *Normal uranium feed requirement*



$\Delta/P = [V(x_P) - V(x_W] - (F/P)\,[V(x_F) - V(x_W)]$

$V(x_P)$, $V(x_F)$, and $V(x_W)$ are the values of $V(x)$ at the assays of product, normal uranium feed, and diffusion plant tails, repectively.

$$V(x) = (2x-1)\ln\left(\frac{x}{1-x}\right)$$

NOMOGRAPH 2. *Separative work requirement*

URANIUM ISSUES AND POLICIES: AN OVERVIEW

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October 1979

A vital element in planning, or in developing of policy, is an understanding of resources that are available. There is a particular interest today in the extent and availability of natural energy resources. Uranium is of special interest in view of the 40–50-year commitment to uranium undertaken when a utility orders a nuclear plant, and when we consider the long-lead time required to develop replacement systems, such as the breeder reactor. Policies and program commitments will in turn influence uranium demands and exploration for new resources and production capability. In this paper, I would like to provide some indication of the current outlook on resources as they impact certain policies in the nuclear field. In addition, I would like to discuss some current public issues regarding uranium, indicating our viewpoints on the issues and what we are doing to clarify the problems involved, as we seek to develop a consensus approach to the uranium-supply question.

NATIONAL ENERGY PLAN

A key statement of the Administration's position regarding energy is provided in the National Energy Plan II which accompanied the Energy Message from President Carter to the Congress on May 7, 1979. The National Energy Plan II is a comprehensive statement of the Administration's approach to energy development and indicates a number of conclusions regarding the appropriate role of the different sources of energy and the activities that should be undertaken in the future to develop and use these resources.

NUCLEAR POLICY

Of particular relevance are the policies and programs for nuclear energy. The strategy for nuclear power has several components: first, "to re-establish the light-water reactor (LWR) with the once-through fuel cycle as a viable supply option, and thereby to ensure that nuclear power will be a significant source of energy for the rest of this century," and second, to "continue development of nuclear power as a potential back-up technology for the next century."

This strategy involves several other components. Primary is the establishment of the safety of nuclear power and resolution of other technical and institutional issues that are now impeding nuclear growth. Three issues are identified: reactor safety, waste management, and reactor siting and licensing. Secondly, we must develop new technologies that permit more efficient use of uranium resources.

As shown in figure 1, this strategy for nuclear power involves several actions: the appraisal of domestic resources, about which I will present more later, the improvement of the uranium-utilization efficiency of light-water reactors, which would eventually be retrofitted to existing LWR's, with a first-step goal of 15-percent improvement in uranium-use efficiency, and the construction of more energy-efficient enrichment plants of the centrifuge type to meet future growth in enrichment demands. This strategy will assist in maintaining lower enrichment tails assays which provide a higher percentage utilization of the ^{235}U content of natural uranium. Advanced isotope separation technology, such as laser separation, may provide even lower enrichment costs and even lower economic tails assays. In addition, there will be continued examination of advanced converter reactor concepts with potentially better uranium-use efficiencies.

Breeder Policy

A key factor in long-term nuclear energy policy is the role of the liquid metal fast-breeder reactor (LMFBR). Breeder policy involves a "hedged" approach, with the flexibility to move to rapid deployment if warranted by future developments. In

- Appraisal of resources (NURE)
- Improvement of LWR efficiency
- Construction of energy-efficient enrichment plant
- Development of advanced isotope separation technology
- Examination of advanced converter concepts

FIGURE 1. *More efficient use of uranium resources*

figure 2, the breeder strategy is based on the concept that uranium availability appears to be adequate for some time and that nuclear power growth for light-water reactors will be much less than previously thought, thus reducing expected demands for uranium. Also there is uncertainty about how economically competitive the LMFBR will be with LWR's. At the present time, these three factors, taken together, do not indicate any need for rapid commercialization of the breeder or for construction of a demonstration plant.

There are substantial uncertainties about the above-mentioned factors, and there can be no definite conclusion drawn at this time as to how these factors will evolve. Thus, the need for a "hedged" breeder approach is needed. The program becomes one of continuing engineering design and of component development for future breeder reactors. A decision to proceed with a demonstration plant may be made as early as 1981, when this issue will be reexamined, or the decision could be deferred until the 1986–1990 period. As far as reprocessing spent nuclear fuel is concerned, there is considerable question as to whether or not it is economically attractive to reprocess to recover uranium and plutonium for refueling light-water reactors. The recovered plutonium also poses a proliferation risk. Therefore, commercialization should be deferred until economically justified, or until plutonium would be needed for refueling breeders.

Breeder Timing

The relationship among uranium economics, nuclear growth, and the cost of breeder reactors, which underlies the strategy, is shown in figure 3. This figure, from the National Energy Plan II, considers three ratios of fast-breeder reactor capital costs relative to LWR's capital costs, i.e. 1.75, 1.5, or 1.25. For each of these three ratios, two uranium price projections are considered—intermediate and high. The prices are expressed as a function of total U_3O_8 used. For example, at 2 million tons, the intermediate price was around $50 and the high price was $80 (1978 dollars). Three cases of nuclear energy growth to the year 2000 are used, i.e. 200, 300, or 400 gigawatts (GWe). Each nuclear-growth case has three subsets of projected nuclear capacity in the year 2020. For the high-cost breeder case, i.e. 1.75 times the cost of LWR's, there would be no economic basis for having the breeder in production until some time after 2020. At a cost ratio of 1.5, with intermediate-cost uranium resources, the post-2020 date is also indicated. However, if uranium prices are higher, and the higher growth nuclear cases are adopted, there could be an economically justified breeder in the 2010–2020 period.

A breeder, of only 25-percent higher capital cost than a light-water reactor, with high-priced uranium and high cases of nuclear growth, could be economically justified in 2000 to 2010. However, with the low-cost breeder, high-cost uranium and lower nuclear growth, the breeder could again be delayed until the 2010–2020 decade. Additional details on this relationship are contained in the report "The Nuclear Strategy of the Department of Energy," DOE/ER-00250, April 1979.

The uncertainties associated with breeder economics, nuclear power growth, and long-term uranium prices underlie the case for pursuing a "hedged" approach.

- "Hedged" breeder strategy a flexible approach.
- Uranium availability, expected nuclear growth, and breeder economics do not indicate a need for rapid LMFBR commercialization. However, there are substantial uncertainties.
- Engineering and component development will be continued.
- Demonstration plant decision could be made in 1981, or deferred until 1986–1990.

FIGURE 2. *Breeder strategy*

NUCLEAR ISSUES

From this quick review of nuclear policy, I would like to turn to more specific uranium-related matters, covering subjects which are somewhat controversial and which are identified as issues. Key current issues are listed in figure 4. The LMFBR continues to be a key nuclear issue. The LMFBR issue is related to concepts of uranium supply, and the resolution of LMFBR issues will impact longer term uranium demands. Some factors regarding the LMFBR have already been discussed. However, employment of the breeder raises additional concerns regarding nuclear weapons proliferation and appropriate safeguards procedures. Technical and institutional aspects of these concerns are considered by many to require further development. Until these elements are resolved, there will continue to be a tendency to defer commercialization of technologies that may use plutonium.

A related aspect to the breeder issue is the question about the capacity of once-through light-water reactors that can be supported by domestic uranium supply. The LWR nuclear growth which we can sustain is a key indicator as to when we have to proceed with other nuclear options, such as plutonium, advanced converters, or the LMFBR, and whether or not to develop other electric energy sources, such as solar, fusion, or geothermal energy.

URANIUM SUPPLY ISSUES

Resources

The second group of issues listed in figure 4 relate to uranium supply. The basic questions are the magnitude of uranium resources in the United States and the adequacy of those resources to meet long-term needs. This issue is not likely to be resolved until there is a more complete assessment of the U.S. resources. We will be hearing more about U.S. Department of Energy (DOE) resource programs, particularly the National Uranium Resource Evaluation (NURE) program, at this seminar. The concerns about resource levels are fundamental and are frequently the key point in the debate about the long-term development of nuclear energy. There are those at one extreme who feel that planning should be based only on ore reserves. This, however, is an unrealistic basis for long-term nuclear energy planning and would lead us into very unwise decisions. On the other hand, there are those that feel there are virtually unlimited resources, and we need only to continue to explore to find what we need. While it may be reasonable to expect that there will be further expansion of resources, it would be risky to just simply assume that there would be any quantity of resources as might be needed in the future and that those resources would be available at a cost that will maintain economically competitive light-water reactors.

- Nuclear
  LMFBR deployment
  LWR reactor capacity supportable
- Raw materials
  Magnitude/adequacy of uranium resources for long-term needs
  Production capability outlook—long term
  Economics of long-term uranium supply

FIGURE 4. *Current issues*

Production Capability

The second issue regarding uranium supply is the long-term production capability that is attainable from the estimated resource levels. This issue involves questions concerning the discoverability of resources and the ability of industry to develop the necessary mining and milling facilities, and to produce at rates that would be adequate to meet projected scenarios of light-water reactor growth. Even though resources are large, there are limitations on how fast these resources can be put into production, and there are limitations on the rates of production that could be sustained. Since light-water reactors require a 10-year period to construct, and they will operate 30 years or more, a reactor order is a long-term commitment to uranium. There must be long-term assurance to a utility that the fuel for a reactor will be delivered when needed. Projecting the discovery and production of the lower reliability potential resources, such as possible and speculative, as must be done for a long-range look, poses particular problems and uncertainties.

Uranium Economics

The third item in the uranium issues area involves the economics of long-term supply. In figure 3, which shows the factors determining breeder competitiveness, it is clear that uranium prices are very significant. If uranium prices rise to certain levels, given other assumptions, the breeder becomes an economically viable option. There are similar economic relationships between light-water reactors and other electric sources. LWR's must continue to be a viable economic option against coal in significant parts of the country, if they are going to continue to be utilized. It would seem unlikely that there will be a strong incentive to use LMFBR's, if we do not have extensive utilization of light-water reactors.

Fast Breeder Reactor Capital Cost[2]	U_3O_8 Price	Installed Nuclear Capacity (Gigawatts Electric)								
		200			300			400			← Year 2000
		400	500	600	500	600	700	600	700	800	← Year 2020
1.75	Intermediate	After 2020	After 2020	After 2020	After 2020	After 2020	After 2020	After 2020	After 2020	After 2020
	High	After 2020	After 2020	After 2020	After 2020	After 2020	After 2020	After 2020	After 2020	After 2020
1.50	Intermediate	After 2020	After 2020	After 2020	After 2020	After 2020	After 2020	After 2020	After 2020	After 2020
	High	After 2020	After 2020	After 2020	After 2020	After 2020	2010-2020	2010-2020	2010-2020	2010-2020
1.25	Intermediate	After 2020	After 2020	After 2020	After 2020	After 2020	After 2020	After 2020	2010-2020	2010-2020
	High	2010-2020	2010-2020	2010-2020	2010-2020	2000-2010	2000-2010	2000-2010	2000-2010	2000-2010

Legend: 2000-2010 (dark shading); 2010-2020 (light shading); After 2020 (unshaded)

[1]Assumes 15-percent improvement in U_3O_8 utilization

[2]Relative to a light-water converter reactor

FIGURE 3. *Timing of the need for a fast breeder reactor in the long term*[1]

Related to the economics of uranium supply is the concern about the nature of the uranium resources that we may have to utilize. There has been increased interest in using known lower grade ores and exploring for new ones. Average production grades have been reduced. The extent and nature of U.S. lower grade resources that will be available over the long term is unknown. The additional low-grade resources in known sandstone deposits do appear to be limited. If we are going to identify significant new low-grade resources, we probably will have to find new deposits, or new types of deposits, or perhaps revert to very low-grade deposits, such as the Chattanooga Shale. Recovery of coproducts, particularly syncrude, from the Chattanooga Shale, may provide uranium at a cost that would be of interest as fuel for light-water reactors. However, the technology, environmental acceptability, and timing of use of resources such as shale are very uncertain.

Uranium Demands

There is a second group of less controversial issues that may be identified as "concerns" (see figure 5). These concerns do not involve adversary points of view but rather are matters that need continuing review and study. The first of these is the future growth of nuclear capacity and related growth in uranium demand. There is considerable uncertainty on this subject, which involves utility ordering or lack of ordering of additional nuclear power plants, the time required for nuclear plant licensing and construction, and the fuel cycle practice that will be followed. These factors have been difficult to assess and will need to be more clearly defined.

Near-Term Exploration and Production

While the capability and desire of industry to explore and produce uranium as needed is an issue in relation to long-term supply, the near-term is much less of a problem. Most of those who have studied this matter conclude that industry has the capability to do the necessary exploration work and to develop the mines and mills that will be needed to meet demands for the next decade, and that industry will have the desire to do so as long as prices and markets are attractive. There is a need to continue to study and report on industry activities and plans and to analyze industry capabilities as a basis for comparison with projected demands.

Uranium Prices

Uranium prices are of concern both to buyers and sellers, although viewpoints may differ. There is continuing need for clarifying current uranium prices and future price trends. Clearly, questions of the extent of resources, exploration success, and industry production capability will have a major role in determining future prices. Projection of prices is very difficult. DOE is endeavoring to develop improved methodologies for gathering and reporting price data and for projecting and analyzing potential future price movement. Emphasis is primarily on examining the parameters of future price movement and not on forecasting.

Lands and Regulations

Land availability and regulation of mining and milling are factors that are of increasing concern to industry and government. The diminishing availability of lands favorable for uranium complicates resource appraisal and analysis and industry exploration and production planning. The increasing regulatory complexities of uranium mining and milling and the uncertainties of new and evolving federal and state regulation are confusing and frustrating. Land availability and mining and milling regulation are not primary responsibilities of DOE. However, DOE does strive to provide relevant information to other agencies, such as the Forest Service and the Bureau of Land Management, to assist them in developing sound land-use decisions.

Foreign Uranium

There is an increasing apprehension about the potential impact of additional foreign supply coming into the U.S. market place. There are those who believe that the United States will tend to be the high-cost world producer, particularly when compared to the new low-cost deposits, such as those

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- Nuclear growth and uranium demands
- Capability and desire of industry to explore and produce
- Uranium prices
- Land availability
- Regulations of mining and milling
- Foreign supply—competition

FIGURE 5. *Concerns*

in the Northern Territory of Australia and in northern Saskatchewan. At the same time, the restrictions on enrichment of foreign uranium for the United States' end-use are being removed. However, at this time, it appears that foreign uranium demands will be sufficient to significantly draw on available foreign supplies. There should be no great pressure on these suppliers to market aggressively in the United States at prices that are significantly below competitive prices for domestic producers. It is clear that the foreign governments involved are attempting not to disrupt market prices but are seeking to assure as high a price as possible for their products. DOE will continue to monitor foreign supply developments, domestic procurement of foreign supply, and potential impacts on the U.S. industry.

DOE Raw Materials Program

Having reviewed some of the policies and issues regarding nuclear power and uranium supply, a review of the related programs of DOE is appropriate. DOE has a comprehensive program to evaluate U.S. resources and the production capability that may be achieved from the estimated resources, to consider economics in the appraisal of the resources and their availability, and to improve related technologies. This activity, largely the responsibility of the Grand Junction Office, is supplemented by surveys from the Washington, D.C., office of DOE on uranium marketing activity and prices and by participation in cooperative international activities to appraise world resources and supply.

Ore Reserves

A key part of the DOE resource program is the estimation of ore reserves. This activity was started in 1952. The estimates are made by DOE geologists and engineers drawing from industry-supplied basic data, primarily gamma-ray logs. The estimates are uniformly done by methods that have evolved over the years and which are at the state-of-the-art. As a result, DOE undoubtedly has the most comprehensive and reliable ore-reserve data for any metal or fuel. The cooperation of industry in supplying the basic data is a major factor in the success of this program.

Potential Resources—National Uranium Resource Evaluation (NURE)

Evaluation of resources beyond ore reserves was initiated by the Atomic Energy Commission in the late 1950s. Until 1974, efforts were largely on the resources of the known mining districts. In the early 1970s, there was increasing concern and controversy about long-range U.S. uranium supply for national energy planning, as a basis for developing orderly and reliable growth of light-water reactor capacity, and for assuring timely transition to the breeder. A study, the National Uranium Resource Evaluation (NURE), was initiated in 1974 to provide a comprehensive and systematic appraisal of U.S. uranium resources (see figure 6). The strategy of the program is to collect existing data and to develop additional primary field information as the basis for the appraisal. Data is gathered basically by airborne radiometric surveys and hydrogeochemical and stream-sediment surveys, supplemented by geologic studies and, in some cases, by drilling of field areas. This information together with studies of areas where deposits are known to occur, which defines geologic favorability, provides the means for estimates of resources by the geologic analogy approach. NURE is organized, planned, and compiled on 620, 1-degree by 2-degree quadrangles, of the National Topographic Map Series (NTMS).

This systematic quadrangle program is supplemented by project studies of specific areas identified as having geology similar to that in foreign world-class types of deposits. While these areas will be studied at some time in our systematic quadrangle evaluation, early and intensive study of specific attractive areas can speed recognition of possible important new uranium areas and add to resources more quickly. We are also performing special studies of intermediate-grade resources, primarily in the grade range from 0.01 to 0.05 percent U_3O_8. This grade of resource has not received much industry attention in the past. While these resources are likely to have higher

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Systematic and comprehensive appraisal of U.S. resources

Field data generations

- Radiometric and HSSR surveys
- Geologic studies and drilling

Quadrangle planning and reporting units

Flexible approach to quadrangle evaluation

World-Class and Intermediate-Grade Studies

Reports

- 1980 on 116 priority quadrangles
- 1983 on 250 priority quadrangles

FIGURE 6. *NURE*

costs than currently mined deposits, they are relevant to long-range planning as they can produce economic fuel for light-water reactors.

The current program plan projects completion of the quantitative assessment of 116 priority quadrangles by the end of fiscal year 1980 and a report on the findings for 1981 decisions on nuclear planning. A comprehensive report will be issued in 1983 covering a cumulative total of 250 quadrangles, and a report in 1985 will cover 400 quadrangles.

The DOE program strategy involves a detailed geologic evaluation of all of the quadrangles containing ore reserves—probable or possible potential resources. Other quadrangles will be evaluated in a varying manner depending on findings of an initial review using available geologic information and the results of the airborne and/or hydrogeochemical surveys. These surveys are expected to provide additional field evidence that either will confirm that an area has no indication of favorability for uranium deposits or indicate quadrangles or portions of quadrangles that warrant additional detailed study. These additional studies may include, as appropriate, additional field surveys or drilling. The screening process will provide a basis for ordering quadrangle evaluation plans to assure that early effort will be on those areas likely to provide the greatest additions to the national resource base. In this manner, DOE expects to complete a comprehensive survey, identifying uranium areas that may have been overlooked and to concentrate DOE's efforts on the areas likely to have resources. The program will continue to include studies of world-class and intermediate-grade type deposits.

Production Capability

While knowledge of ore reserves and potential resources is fundamental to understanding future supply, such information by itself is inadequate and must be supplemented by studies of the discoverability and producibility of the resources. We must know the annual production rates that are attainable if we are to know the level of reactor capacity that can be supported, and hence at what future time domestic resources may not be able to meet our needs. We are continuing to study production capability and those factors that limit future production rates. An expanded system for performing these studies in a more rapid and flexible manner is under development—to be in operation next year.

Economics

Nuclear decisions will be heavily influenced by the relative costs of electricity that can be produced. Therefore, information on the costs of discovery and production is essential to sound appraisal of resources in addition to knowledge on the magnitude of the resource base and producibility. Such cost information provides insight on the prices at which the uranium might be available.

We have traditionally performed our reserve and potential resource appraisal on the criteria of forward costs, that is, the cost that will be required to produce the estimated resource. This appraisal has proved to be a workable approach considering the information available or which can be reasonably estimated using engineering approaches. However, DOE recognizes that there are limitations to this criteria for analyzing the possible future costs of uranium to buyers. Therefore, DOE is working to develop data that will indicate the total costs of producing the resource, including past or sunk costs and other costs not included in a forward-cost analysis. DOE is also working on approaches that indicate the prices which would be required assuming some specific return on investment. The new production capability system will aid in performing this work. DOE expects this information will be useful to industry as well as government.

Drilling

DOE drilling activity seems to generate much interest and concern. The purpose for DOE drilling is to seek and develop additional information for assessment of potential resources. Drilling is a data-gathering effort similar to DOE's airborne or hydrogeochemical surveys. DOE is not attempting to locate and delineate orebodies as industry does in its exploration work. Drilling efforts in an area will usually be very limited. Most of DOE's drilling is in areas which DOE seeks to evaluate for the first time in connection with the quadrangle evaluation program and with the World-Class or Intermediate-Grade Programs. Such areas generally have little or no current industry activity.

In the last few years as part of our effort to upgrade the quality of resource estimates, DOE has also drilled in areas with estimated potential resources seeking to confirm the assumptions underlying the estimates. Drilling in the Chaco Canyon area, New Mexico, was to confirm resource estimates. This type of drilling tends to be closer to industry work and has evoked the most comment from industry. Industry data may be available in certain of the planned project areas, and with use of this data, DOE drilling may not be warranted, or the DOE drilling program could be modified. DOE, with the valuable assistance of the Atomic Industrial Forum (AIF) Mining and Milling Committee, has been working to assure we have all available data. This assistance has proved to be very helpful in our planning. When additional industry data becomes available, DOE drilling plans will be reconsidered.

DOE-Industry Relationships

Much of the program success can be attributed to excellent cooperation from industry over the years. We value the close relationship and trust that has developed. The counsel which is received helps to assure that programs are sound and useful. Therefore, some comments should be made concerning DOE's policies in this area (see figure 7).

The intention in planning the program is to minimize overlap of industry and DOE efforts. DOE does not intend to undertake activities that industry is doing, or is likely to do, in the time frame relevant to these studies. DOE seeks to build on industry efforts and to work on projects otherwise undone. Obviously to implement these efforts, DOE must know what industry is doing and must have some expectation of obtaining the results of the work. While the DOE program has as its primary mission the provision of information for national energy planning, we clearly recognize the value of the information to the uranium exploration and producing companies and the utilities and related companies. Hence, DOE endeavors to make this information available in a timely and useful manner. Such information release will also provide a means to stimulate industry activity and provide additional information to us in the future.

The expertise, experience, and knowledge of industry are well recognized by us. We, therefore, solicit your views on DOE programs and findings and on the problems encountered by industry. These meetings held in Grand Junction with company personnel have provided an excellent means of exchanging views.

Underlying this relationship is our continuing concern about the confidentiality of information that we receive from industry. We assure you that we have maintained and will continue to maintain the strictest adherence to holding in confidence the information we receive from the companies. We have been completely successful in maintaining confidentiality of such information, and we restrict access to such information to those DOE people who are working on the specific subject matter. There has been increasing concern about our ability to maintain confidentiality of data. DOE has not deviated in any manner from strict maintenance of confidentiality of information received, and we pledge to make every effort to continue to do so.

International Concerns

The topics covered so far are primarily related to the United States. There are, in addition, a number of concerns in the international area that should be covered. It is our view that, in spite of intensive exploration efforts over the past 25 years or so, the world's uranium resources are poorly known, even in countries that have received the most exploration work. The dramatic discoveries in the Northern Territory of Australia and in northern Saskatchewan of Canada make this point clear. There are, in addition, areas with favorable geology that have had virtually no exploration or resource appraisal work. Efforts on world resources can lead to better understanding of long-term supply prospects and very likely will lead to expanded world-uranium supply.

Multinational efforts through international organizations which involve producing and consuming countries are the primary focus of our efforts; we judge that such efforts are likely to be the most fruitful and will produce the most acceptable programs for the countries involved. DOE is participating in activities of the Organization for Economic Cooperation and Development, Nuclear Energy Agency (OECD-NEA) and the International Atomic

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Not duplicative of industry work
Builds on industry activities
DOE output aids industry exploration and planning
Timely release of DOE developed information
Company confidentiality carefully maintained

FIGURE 7. *DOE relationship with industry*

Energy Agency (IAEA). The work of the NEA-IAEA Joint Working Party on Uranium has produced authoritative reports on world-uranium resources and production since 1964. A more recent, but increasingly important, activity is the International Uranium Resources Evaluation Project (IUREP) which also involves the NEA and the IAEA. The initial product is a report "World Uranium Potential—1978," which involved the appraisal of some 185 countries. IUREP is now undertaking short, collaborative, field studies in selected countries with particular potential for uranium which have not been adequately explored or evaluated. The current effort is financed by six countries that are primarily producers and the European Economic Community. DOE also participates in NEA-IAEA activities regarding exploration techniques, and mining and processing practices.

SUMMARY

U.S. policy is to reestablish the viability of nuclear energy and to expand the useful energy derived from uranium. A comprehensive assessment of U.S. uranium resources is a key part of this effort. This assessment should lead to resolution of issues regarding adequacy of U.S. uranium resources and production capability to meet long-term need in an ecomomic manner. DOE programs on ore-reserve estimation, resource appraisal (particularly NURE), and production capability analysis are responsive to these information needs, as well as concerns regarding uranium demand, market growth, uranium prices, and foreign supply and demand. The cooperation of industry, particularly in providing basic information needed for DOE studies, is a vital element of this activity.

THE U.S. URANIUM MARKET: 1978-1979

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October 1979

INTRODUCTION

In last year's marketing paper presented at the Uranium Industry Seminar, we noted that U.S. buyers and sellers were "watching" market activity closely, but there were fairly stable prices and little buying activity. The uranium market during the past year can be described as more active but certainly not bullish. Since demand has slipped while supply has been expanding, the price of uranium for delivery in the near term has decreased and can be said to be approaching an equilibrium level. This paper will present recent information on uranium marketing activity gathered in DOE surveys. Examining these data enable us to document the market situation and, hopefully, provide some insight to future trends in uranium marketing.

MARKET SURVEYS

Our data on uranium marketing activites are obtained by conducting two surveys each year: a January survey requesting information on all aspects of the uranium market—sales/purchases, inventories, imports, exports, prices, etc.—and a July survey which just collects data on prices and delivery schedules (figure 1). The comprehensive January survey involves both uranium producers, and potential producers, and uranium buyers—utilities and reactor manufacturers. Thirty-five producers and 66 buyers responded to the January survey which covers virtually the entire industry. The July price survey only requests data from buyers, the group which supplies price information for the January survey.

PROCUREMENT—DOMESTIC URANIUM

Procurement—1978 and First-Half 1979

U.S. buyers made additional purchase commitments of 23,000 tons U_3O_8 from U.S. primary producers during 1978 (table 1), compared to 12,000 tons during 1977. However, the net addition to delivery commitments during 1978 was 12,200 tons compared to 11,500 tons in 1977, owing to greater reductions to prior commitments during 1978 than in 1977. These reductions to prior commitments in 1978 resulted from revised schedules of utility captive production and, to a much lesser extent, nondelivery of material under litigation.

Table 1 also shows additional procurement during the first half of 1979 according to data gathered in our July price survey. In my last year's Seminar paper, an "apparent" net reduction in U_3O_8 procurement commitments during the first half of 1978 was reported. We used the term "apparent" because, in last year's price survey, data on prices and associated delivery commitments were requested only for the years up to and including 1985. Thus, any rescheduling of commitments from pre-1986 to post-1985 delivery was not recorded. To avoid this problem, the present price survey requested data on prices and delivery commitments to the year 2000.

FIGURE 1. *Uranium marketing activity surveys annual—1968 through 1978*

Published as report "DOE/RA-0038, Survey of U.S. Uranium Marketing Activity"

<u>1978 Survey</u>

Information was provided by:
- 61 utilities
- 5 reactor manufacturers
- 35 uranium producers

<u>Price Surveys</u>

Annual—1973-1975
Semiannual—January and July since 1976

TABLE 1. *Domestic commercial uranium deliveries and commitments to U.S. buyers: 1978 and 1979*

	Tons U_3O_8				
	As of 1/1/78	During 1978	As of 1/1/79	During first Half 1979	As of 7/1/79
Past deliveries plus forward commitments	300,700		312,900		329,700
Total new purchases		23,000		12,300	
Changes to prior commitments		(10,800)		3,500	
Net change		12,200		16,800	

The July 1979 price survey shows that new purchases were 12,300 tons U_3O_8 during the first half of 1979, slightly over half the amount of new purchases during 1978. In contrast to 1978 activity, the changes to prior commitments during the first half of 1979 resulted in a net addition to commitments. The changes-to-prior-commitments number represents the sum of additions to and reductions in commitments reported in the prior survey. The 3,500-ton positive change shown for the first half of 1979 is primarily from additions to utility captive production schedules.

Delivery Schedules of Domestic Commitments

Annual domestic uranium delivery schedules as of January 1, 1978 and 1979, and July 1, 1979, are tabulated in table 2. Comparison of delivery schedules as of January 1, 1979, and July 1, 1979, shows that, except for the years 1982, 1989, and 1990, the amounts to be delivered increase for each year over the 1979 to 1990 period. However, the cumulative net increase in delivery commitments over the 1979 to 1990 period is less than half of the increase for the 1991 to 2000 period. Note that the quantities scheduled to be delivered over the 1991 to 2000 period are probably not as "certain" as those to be delivered in earlier years since they represent, to a large degree, estimates by utilities of production from properties they control (captive production). Such estimates necessarily decline in accuracy the further in the future that they are projected.

The schedules of domestic delivery commitments discussed above include contract options and quantities in contracts under litigation, as well as "firm" commitments. It should be noted that some contracts in the "firm" category contain clauses which permit their cancellation by either the seller or buyer if cost of production or price does not meet certain standards. Figure 2 graphically depicts the annual amounts of January 1, 1979, commitments in contracts under litigation and option. Information from the January 1, 1979, survey is used because it is more complete than that in the July 1979 price survey, but the July results would be similar. While both the annual amounts of material under option and under litigation are relatively small, the total of the two is worth noting. The importance of these components of supply will become evident later in the paper when supply is compared with requirements.

In our data on delivery commitments, we include material in contracts under litigation unless it is clear that the uranium has not been, or clearly will not be, delivered. This practice follows from the assumption that all or some of the uranium in such contracts is likely to be delivered. Since it is likely that any resolution of contract disputes will result in some price changes, prices and quantities of material under litigation are not included in our reporting of prices.

URANIUM PRICES

Contract Prices

Table 3 shows average "contract" prices in year-of-delivery dollars as of the two 1979 surveys. "Contract" prices refer to those prices in contracts where price and means of escalation, if any are determined when the contract is signed. Price settlements of market price contracts are included with contract prices since, as settled prices, they are similar to contract prices. While average prices increased between the surveys, part of this increase may be attributable to buyers' changed perception of inflation in estimating prices in terms of year-of-delivery dollars for each of the two surveys. Another reason for the increase relates to the addition of higher prices of market price contracts that were settled between the two surveys. Also shown in table 3 as

TABLE 2. *Annual uranium delivery commitments—domestic primary sources to domestic buyers*

Year of Delivery	As of 1/1/78	As of 1/1/79	As of 7/1/79
	Thousand tons U_3O_8		
1979	17.7	19.1	19.6
1980	19.6	20.0	20.7
1981	19.6	19.3	19.4
1982	19.5	19.4	19.1
1983	17.0	17.8	17.9
1984	13.0	14.1	14.5
1985	11.7	12.8	13.0
1986	9.1	10.9	11.0
1987	8.8	10.5	10.9
1988	7.9	9.5	10.0
1989	7.5	9.4	9.1
1990	6.4	7.3	6.4
1991-2000	16.1	19.3	34.6

Includes optional quantities

"Coverage of Prices" are the percentages of contract price and settled market price commitments for which price data were provided in both surveys.

Figure 3 depicts the price distribution, in $5 increments, of contract price and settled market price commitments for the 1979 to 1989 period as of the July 1, 1979, survey. In a sense, figure 3 represents a distribution of average prices as many respondents have more than one contract in any year. These distributions are also presented in terms of year-of-delivery dollars, with those increments covering 15 percent or more of any year's commitments shaded.

Floor Prices

Most market price contracts, which call for price to be based on prevailing prices at or sometime before delivery, have floor (base) price provisions that set a lower limit to the eventual settled price. Table 4 shows the distribution of market price commitments by type of floor value provisions as of July 1, 1979, for the 1980 through 1993 period. Some 15 percent of market price commitments for this period have no floor value provision, 25 percent have floors related to the seller's cost of production, and the remaining 65 percent have floor prices.

Table 5 presents, in terms of year-of-delivery dollars, average floor prices of market price contracts reported as of the January and July 1979 surveys. These floor prices are similar to contract prices in that they are determined, with means of escalation, if any, when the contract is signed. Average floor prices range from 1.3 to 2.0 times higher than average contract prices. A notable reduction in average floor prices occurred between the January and July 1979 surveys.

Figure 4 gives the price distribution of floor prices in market price contracts along with average floor prices. As in the case of the

TABLE 3. *Average contract prices—year-of-delivery dollars*

	As of January 1, 1979		As of July 1, 1979	
Year	Price Per Pound of U_3O_8	Coverage of prices (%)	Price Per Pound of U_3O_8	Coverage of prices (%)
1979	18.95*	92*	21.60*	94*
1980	20.15*	91*	22.65*	89*
1981	24.60	87	30.10*	86*
1982	24.85	85	29.15*	84*
1983	26.05	83	30.15	82
1984	28.05	86	30.85	87
1985	28.95	84	33.65	86
1986	32.10	74	35.70	76
1987	34.25	75	37.65	77
1988	40.05	71	42.75	80
1989	--	--	46.10	80

*Includes price settlements of market price contracts distribution of contract prices, the floor price distribution represents a distribution of averages to the extent that buyers report prices for more than one market price contract with a floor price in any one year. The variance in floor prices is very great, reaching a range of about $35 and $120 in 1993. It is interesting to note that the majority of market price commitments with floor prices are at price levels at either end of the ranges, and very few are in those $5 increments where the averages fall.

The large percentage of commitments at prices $35 to $40 suggests that either many contracts with floor prices do not include a mechanism for price escalation or some companies did not report escalated prices. However, it is known that some market price contracts with floor prices do not contain a mechanism to escalate these prices for inflation. Also, one contract was previously reported incorrectly, giving the ceiling price instead of the floor. This correction, plus the fact that market price contracts for which prices were settled during the first half of 1979 had floor prices in the upper end of the ranges, would account for some of the reduction in average floor prices. In any case, it would appear that in terms of 1979 dollars most floor prices fall in a range of $35 to $45.

Price Settlements of Market Price Contracts

The top half of table 6 presents, in year-of-delivery dollars, the price settlements of market price contracts as of January 1, 1978, July 1, 1978, January 1, 1979, and July 1, 1979. We use the term price settlements of market price contracts since we define a market price contract as one where price is *related to* the market price at or sometime before delivery. Thus, a price resulting from a market price contract may not be, and often is not, the market price. For example, if a market price contract contains a floor price which is higher than the market price at the time of settlement, the price paid would equal this floor price. Even though the price paid in this case is not equal to the market price, the contract is labelled

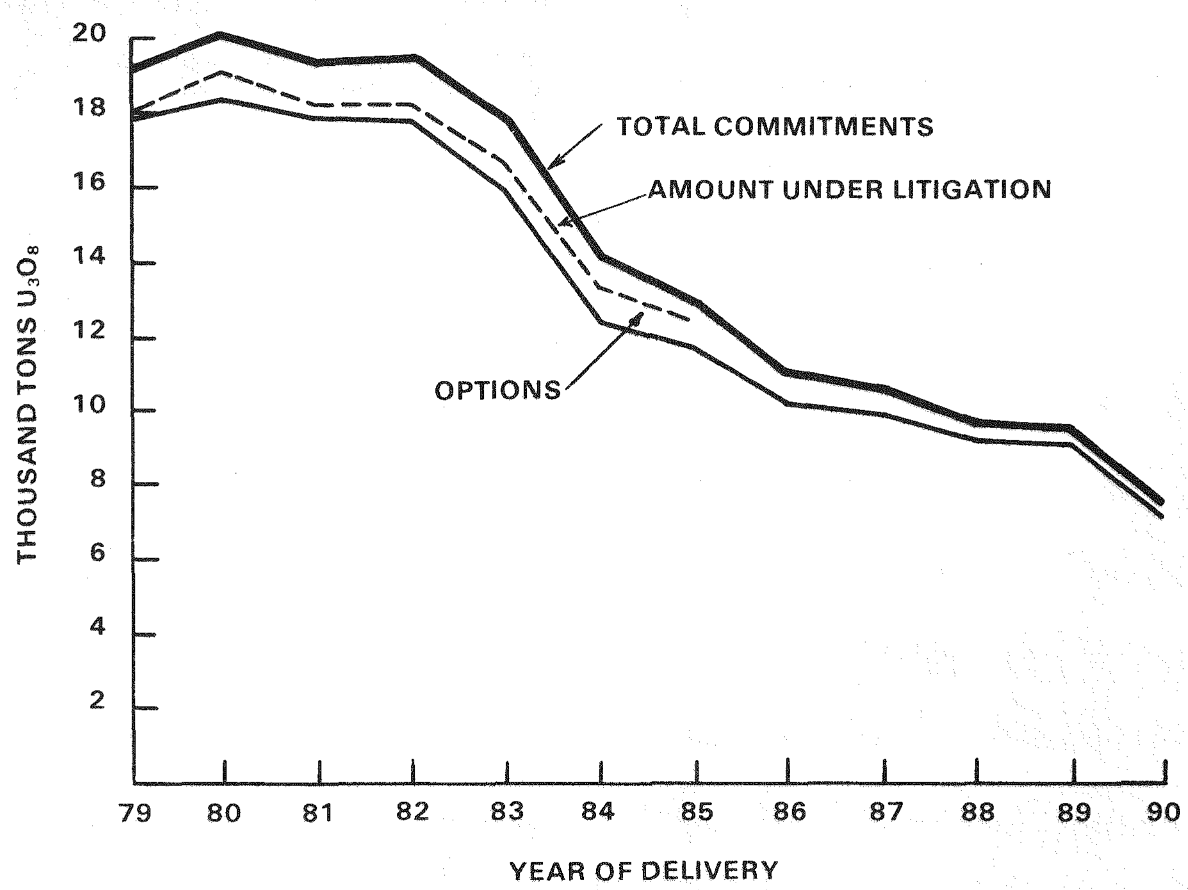

FIGURE 2. *Domestic uranium commitments to domestic buyers as of January 1, 1979*

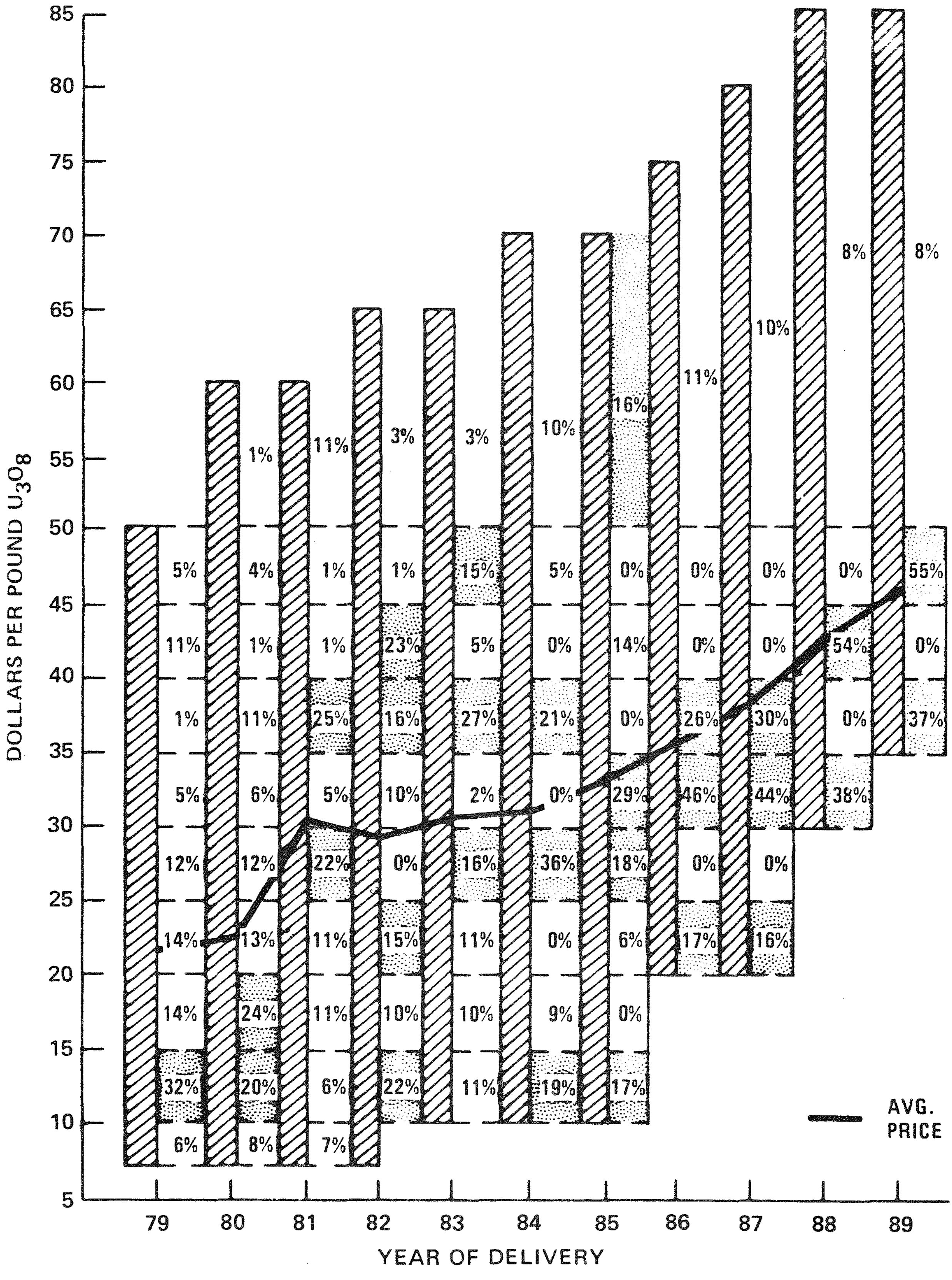

FIGURE 3. *Distribution of U_3O_8 prices, 7/1/79 contract prices and market price settlements*

TABLE 4. *Floor price arrangements in market price contracts July 1, 1979*

Year of Delivery	Price Base	Cost Base	No Base Value
	Percentage of market price deliveries		
1980	69	12	19
1981	73	9	18
1982	72	10	18
1983	56	27	17
1984	51	37	11
1985	57	37	6
1986	54	35	11
1987	55	34	11
1988	56	24	20
1989	54	26	20
1980-1989	60	25	15

market price because the market price must be determined, or referred to, before the final price can be settled. Other examples of market price contracts where the settled price does not equal the market price include those where price is a weighted average between market price and some predetermined price and those where the price paid is a discount from the market price.

In absolute terms, price settlements of market price contracts have not changed much since January 1, 1978. However, since we have experienced a high rate of inflation over this period, the corresponding real prices have declined. This decline is shown in the bottom half of table 6 where all prices listed in the top half are expressed in terms of 1977 dollars. These prices have been adjusted using the Gross National Product (GNP) deflator, including an estimate of the deflator for 1979. It is evident that all adjusted prices are below the 1977 settled price of $41.50 as of January 1, 1978.

Several additional points should be made with respect to the price settlement data. First, the data represent, on the average, a little over two-thirds of all such price settlements. Second, while settled prices should not change between surveys since they are, by definition, "settled," quantities related to these prices do change. Thus, although it is possible to derive mathematically an average price that would produce the change in price between any two surveys, this derived price might have little meaning. A further complication is, as mentioned before, that these average settled prices do not always represent the average market price.

There are some further statistics on the 1979 settled price as of July 1, 1979. The 1,400 tons U_3O_8 represent twelve different contracts for ten companies. While the price presented is the mean

TABLE 5. *Average floor prices of market price contracts (year-of-delivery dollars)*

Year	As of January 1, 1979		As of July 1, 1979	
	Price Per Pound of U_3O_8	Coverage of prices (%)	Price Per Pound of U_3O_8	Coverage of prices (%)
1979	39.45	72	43.40	100
1980	44.20	64	42.55	62
1981	48.00	69	43.20	66
1982	47.40	64	46.00	72
1983	53.35	67	47.45	83
1984	57.60	63	49.45	76
1985	60.90	64	50.60	79
1986	64.60	63	52.70	79
1987	68.40	63	54.85	80
1988	73.55	72	57.85	87
1989	--	--	59.85	93
1990	--	--	62.10	100
1991	--	--	64.90	100
1992	--	--	66.60	100
1993	--	--	78.00	100

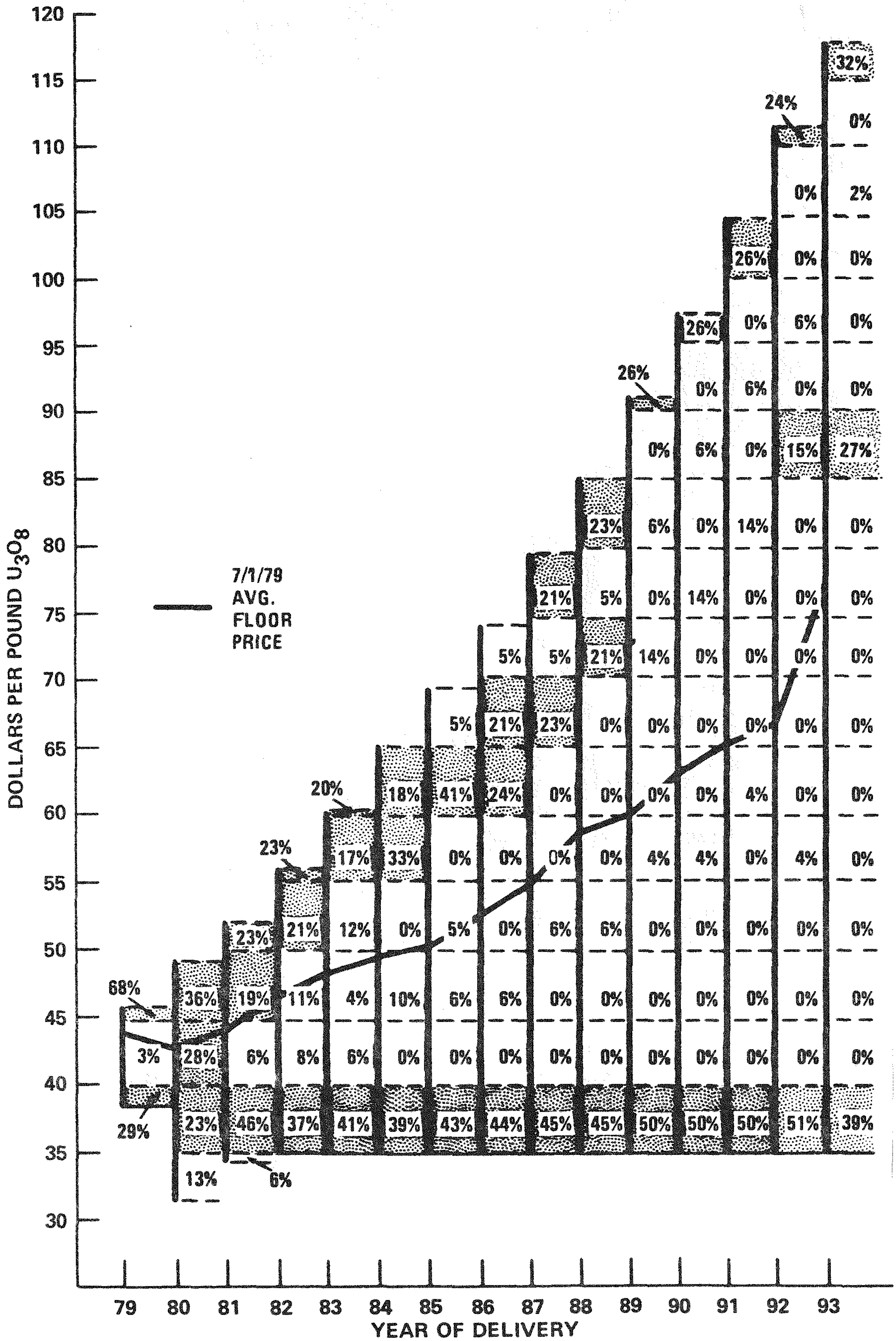

FIGURE 4. *Range of reported floor prices of market price contracts—7/1/79 survey*

(average of prices weighted by the tons), the median (mid value) is also $43.55. Three contracts where price settlements differed from the market price were reported by two utilities. In two of these cases, the market price was higher, and in one case, it was lower.

Procurement Arrangements and Trends

Although there are a number of variations in uranium contracts, we request and report data on types of procurement in three categories: contract price, market price, and other. The other category refers to procurement arrangements that do not fall into the contract price or market price categories and mainly includes arrangements where utilities are directly involved in uranium production operations—captive production. As of the July 1, 1979, survey, 72 percent of the quantities listed in the other category was captive production.

Table 7 presents the annual distribution of types of uranium procurement for the 1979 to 1989 period as of the July 1979 survey. The percentage of contract price procurement declines from a very high level of 75 percent in 1979 to 16 percent in 1986, and from then on, contract price procurement represents the least used approach. However, since a greater number of delivery commitments have been made for those years in which the percentage of contract price procurement is relatively high, contract price procurement represents the dominant form of contracting for the 1979 to 1989 period. Note that these percentages apply only to existing delivery commitments and will change as more uranium is procured for delivery in this period.

Uranium contracting has evolved to meet the changing conditions of the uranium market. Through the year 1974, a period in which uranium prices were relatively stable, contract price procurement was used almost exclusively. In 1975, when the price of uranium experienced its most rapid increase, market price procurement, an approach which allowed producers to capture the full extent of price increases became dominant. The rapid increase in prices during 1975 motivated some utilities to become directly involved in uranium production as a method of controlling their fuel costs and assuring their uranium supply. This involvement was evidenced in 1976 when utilities developed firm production schedules and other procurement was the major approach used. During 1977, market price procurement again became the dominant form of procurement. Although slightly over half of 1977 procurement was market price, half of the remaining procurement was contract price which called for delivery in 1977 and 1978, a time period for which market price contracts would be inappropriate. In 1978, market price procurement accounted for 70 percent of new contracting with the other category accounting for 20 percent.

Results from the July survey indicate, for the first half of 1979, that none of the three approaches accounted for over half of the new purchases. However, there were important variations within each category. For example, between one-third and one-half of new market price procurement called for discounts from the market price, while at least one-half of such contracts do not have floor prices. Also, none of the new procurement listed in the other category is captive production.

TABLE 6. *Price settlements of market price contracts (year-of-delivery dollars)*

	As of 1/1/78		As of 7/1/78		As of 1/1/79		As of 7/1/79	
Year of Delivery	Average Price ($/lb U_3O_8)	Tons U_3O_8	Average Price ($/lb U_3O_8)	Tons U_3O_8	Average Price ($/lb U_3O_8)	Tons U_3O_8	Average Price ($/lb U_3O_8)	Tons U_3O_8
1977	$41.50	800						
1978	$43.65	1,100	$43.65	1,400	$43.80	1,700		
1979			$44.65	600	$44.30	600	$43.55	1,400
			(1977 Dollars)*					
1977	$41.50							
1978	$40.90		$40.65		$40.80			
1979			$38.15		$37.85		$37.20	

* Using GNP deflator.

TABLE 7. *Type of uranium procurement as of July 1, 1979*

	Percentage of Deliveries by Types of Procurement		
Year of Delivery	Contract Price	Market Price	Other
1979	75	16	9
1980	66	21	13
1981	54	28	18
1982	44	33	23
1983	41	39	20
1984	34	40	26
1985	34	38	28
1986	16	46	38
1987	18	45	37
1988	22	40	38
1989	24	38	38
1979–1989	43	33	24

ADDITIONAL MARKET DATA

The following information on the uranium market was gathered as part of our January 1979 survey.

Utility Involvement in Raw Materials Activity

As an alternative way of securing their uranium supplies, some utilities with nuclear power projects have become involved in uranium raw materials activities. Of 61 utilities responding to our January 1979 survey, 26 (43 percent) indicated that they were directly involved in such activities which range from exploration to production. The involvement reported this year represents a reduction from that reported in January 1978 when 30 utilities reported they were active in uranium raw material ventures. Table 8 lists for the January 1979 survey types of activities reported and number of companies involved in each allowing for the fact that utilities can be engaged in more than one activity. Note that providing "front-end" money as part of a procurement agreement would not constitute direct involvement.

Uranium Import and Export Commitments

Table 9 presents the delivery schedules for United States uranium import and export commitments as of our January 1979 survey. In reporting imports and exports, we are concerned with the purchase of foreign-origin uranium intended for use in the United States and sale of domestic-origin uranium for use in foreign countries. Thus, we would not include as either an import or an export the purchase and subsequent reexport of foreign-origin uranium by a U.S. buyer.

The data in table 9 show that, historically, there have been more commercial sales of U.S. uranium to foreign countries than foreign uranium sold here commercially. Exports were greater than imports during 1978, with most exports resulting from spot sales of uranium. However, it must be recognized that before 1977, there was a prohibition on the enrichment of foreign-origin uranium for use in domestic reactors. The limit on enrichment of foreign-origin uranium for domestic use was 15 percent of each customer's needs in 1978, and this percentage increases annually until 1984 when the restriction will be removed completely. As opposed to historical import and export deliveries, future (1979 on) cumulative import commitments of 29,700 tons exceed cumulative export commitments 17,600 tons. However, a large portion of these import commitments is subject to litigation, the outcome of which could affect this comparison.

Most of the export commitments listed in table 9 were made before 1975. Whereas table 9 tabulates the import and export delivery schedules as of January 1, 1979, table 10 shows the import and export commitments made in each year, 1975 through 1978. While commitments for imports exceeded those for exports in 1975, the reverse was true for 1976, 1977, and 1978, with total export commitments made from 1975 to 1978 greater than import commitments made during the same period.

Domestic U_3O_8 To Be Available for Sale

Table 11 presents the amount of U_3O_8 over and above current sales commitments that domestic producers estimate they will be able to offer for

TABLE 8. *Uranium raw materials activities by utilities—26 of 61 (43%) reported involvement*

Activity	Frequency
Exploration	23
Control of reserves	11
Mining	7
Production	2

TABLE 9. *Uranium import and export delivery schedules as of January 1, 1979*

Year of Delivery	Thousand tons U_3O_8 — Foreign-origin uranium purchase commitments for domestic end use (Imports)* — Annual	Cumulative	Sales commitments of domestic-origin uranium to foreign buyers (Exports) — Annual	Cumulative
Pre-1978	--	5.3	--	10.0
1978	2.6	7.9	3.4	13.4
1979	1.7	9.6	2.6	16.0
1980	1.7	11.3	1.6	17.6
1981	4.0	15.3	0.8	18.4
1982	3.6	18.9	0.5	18.9
1983	3.3	22.2	0.5	19.4
1984	3.3	25.5	0.4	19.8
1985	3.4	28.9	0.4	20.2
1986-1988	1.75/year	34.2	0.25/year	21.0
1989-1990	1.75/year	37.6	--	--

* Includes 1,500 tons of optional purchases.

sale each year over the 1979 to 1985 period as of January 1, 1978 and 1979. The phrase"be able to offer for sale" indicates that the estimates are related to perceived market conditions and not to how much additional uranium the industry could produce given only technical, geologic, and regulatory constraints.

The January 1, 1978, and January 1, 1979, data are shown together for two reasons. First, comparison of the two sets of numbers indicates the reduction in planned production between the two points in time, although the January 1, 1979, survey had somewhat less complete data; two producers which provided data in January 1, 1978, did not provide data on January 1, 1979. Second, the January 1, 1978, estimates were made when the market situation looked more promising and might provide a better measure of what the U.S. industry could actually produce. Thus, if the market situation were to improvė, actual production could be more in line with the January 1, 1978, numbers.

A possible complication in producers' estimates of what they will be able to offer for sale relates to contract options and amounts of uranium in contracts under litigation. Since, as previously noted, we include such material in our reporting of delivery commitments, these additional amounts of uranium that producers estimate they will be able to offer for sale may not represent net additons to the January 1, 1979, delivery commitments in table 2.

Capital Expenditures

Another indication of domestic producers' perceptions of the future uranium market is their planned capital expenditures as of the January 1, 1978, and January 1, 1979, surveys. Table 12 shows data on actual capital expenditures for new and expanded mines and mills in the year prior to each survey and planned expenditures in the following two years. For the two years (1978 and 1979) that a comparison can be made, there is a reduction in the amounts reported between the surveys although the levels are still substantial.

Unfilled Requirements

In our January surveys, we request buyers to state unfilled uranium requirements for those reactors for which they must supply fuel. Unfilled requirements include the portion of a utility's total annual requirements after consideration is given of its inventories and procurement arrangements. Table 13 lists the sum of unfilled requirements reported in the surveys as of January 1, 1978, and January 1, 1979.

The reduction in unfilled requirements between the January 1, 1978 and 1979, surveys was due primarily to slippages in reactor schedules along

TABLE 10. *New uranium import and export commitments made each year 1975-1978*

Year	Thousand tons U_3O_8 Import Commitments	Export Commitments
1975	4.4	.4
1976	1.8	2.6
1977	1.5	2.6
1978	1.5	5.5
1975-1978	9.2	11.1

with revised enrichment contracts which allowed scheduling of uranium deliveries to coincide with actual reactor needs. New uranium purchases in 1978 also accounted for some of the reductions. Current unfilled demand is likely to be lower both to the extent that there has been additional procurement during the first part of this year, and utilities have made additional demand adjustments for enrichment contracts.

TABLE 11. *U_3O_8 above current sales commitments that producers estimate they can offer for sale as of January 1, 1978,and January 1, 1979*

Year of Delivery	Thousand tons U_3O_8 1/1/78	1/1/79
1979	4.1	1.4
1980	5.0	2.2
1981	8.2	4.0
1982	10.5	6.7
1983	14.0	8.4
1984	16.3	10.1
1985	16.9	10.5
Total	75.0	43.3

Aggregate Supply and Demand

By combining some of the previously presented data, it is possible to develop aggregate supply and demand curves for the U.S. uranium market. Presenting the data in this way can provide certain insights to the market, but there are also limitations in such a presentation.

Figure 5 shows domestic uranium supply and demand as constructed from survey data. Domestic supply is derived by combining January 1, 1979, data on annual delivery commitments from domestic and foreign producers and estimated additional uranium for sale reported by U.S. producers. The limitation on use of foreign-origin uranium should be noted here as actual usage of foreign-origin uranium will differ from the delivery schedule. Also, the fact that purchase commitments, including options and material under litigation, should be recalled as additional factors that could change the shape of the supply curve.

An aggregate demand curve can be derived by adding unfilled requirements reported as of January 1, 1979, to purchase commitments from domestic and foreign sources. Since there has been additional procurement during the first half of 1979, the curve representing purchase commitments from domestic and foreign sources in figure 5 has changed, but the extent to which the market survey requirements curve has changed will depend also on the extent to which unfilled requirements have changed. Inventories of uranium, which are a source of supply available to utilities used in calculating their unfilled requirements, were not included in the representation of either demand or supply. The DOE's Energy Information Administration (EIA) demand forecast is also shown for comparison.

Comparing the supply and demand curves so derived, supply would exceed demand up to the mid-1980s. This relationship only holds if, given all of the other caveats, U.S. producers sell all of their estimated additional uranium supply to U.S. buyers. However, by the same token, this representation does not consider additional foreign supplies that may be sold to U.S. buyers. It is evident that up to mid-1980s the EIA requirements curve is much lower than that derived from marketing survey data. This difference results because the EIA curve, which is an estimate of "true" reactor needs, does not take into consideration enrichment contract requirements or actual purchase commitments and plans.

Inventories

The current level of inventories (both unenriched and enriched) held by uranium buyers (utilities, reactor manufacturers, and fuel fabricators) is 44,700 tons equivalent U_3O_8 (table 14). This amount does not include uranium at the enrichment plants except for that under usage agreements. Of the 44,700 tons, 11,500 tons are enriched uranium. Utilities own 35,600 tons of

TABLE 12. *Capital expenditures for uranium production as of January 1, 1978, and January 1, 1979*

	Millions of dollars		
	Actual	Planned	
As of January 1, 1978	**1977**	**1978**	**1979**
Mine	325	422	373
Mill	167	212	152
Total	492	634	525
	Actual	**Planned**	
As of January 1, 1979	**1978**	**1979**	**1980**
Mine	271	303	283
Mill	156	125	162
Total	427	428	445

which 10,000 tons are enriched). Most of the uranium (39,300 tons) is of domestic origin.

It is evident upon inspection of figure 5 that uranium inventories could continue to build up over the coming years. The degree to which inventories will be built up depends on many factors, including utilities' policies on holding inventories. Table 15 shows information, gathered in our January 1979 survey, on utility inventory policies. The data in table 15 largely relate to inventories of normal uranium although some utilities provided separate information on policies of holding enriched uranium inventories.

TABLE 13. *Unfilled uranium requirements* as reported January 1, 1978, and January 1, 1979*

	Thousands tons U_3O_8	
	1/1/78	**1/1/79**
1979	1.6	0.4
1980	3.0	1.1
1981	5.7	3.3
1982	8.6	4.2
1983	8.0	5.6
1984	12.4	9.5
1985	14.1	12.0
1986	19.5	14.9
1987	23.3	17.0
1988	24.7	20.3
1989	28.1	23.7
1990	28.6	23.5
Total	177.6	135.5

* Assuming tails assay of 0.20 percent, no recycle.

In table 15, inventory policy is tabulated in terms of present amounts held and desired levels to be held. The information on desired levels of inventory is presented as a distribution instead of an overall average because utilities have different size nuclear programs, and the total amount of desired inventory cannot be derived from such an average. Of 35 utilities which characterized their present level of inventory, ten classified it as "excessive." Four of these ten utilities desire to hold one year or less of inventory.

TABLE 14. *Uranium inventories—buyers*

	Tons U_3O_8 equivalent	
	All Buyers	**Utilities**
Normal	33,200	25,600
(Foreign origin)	(5,200)	(3,000)
Enriched	11,500	10,000
(Foreign origin)	(200)	(200)
Total	44,700	35,600
(Foreign origin)	(5,400)	(3,200)

Figure 6 shows the distribution of inventories of normal uranium held by utilities. These inventories are unequally distributed, with the ten largest inventories accounting for 56 percent of the total and the ten smallest only 1 percent. The amount of excess inventories held by utilities would depend on whether or not those utilities holding the largest inventories have large nuclear projects and how much forward supply they want to hold.

To determine the extent of loans and sales made by utilities, the January 1979 survey requested utilities to state any such sales and/or loans they have made for delivery after January 1, 1978. The total amount reported was small—less than 900 tons. Of this amount, less than 200 tons were for delivery in 1979. Thus, utilities have not been very active, to date, as suppliers in the market.

SUMMARY

The level of uranium procurement activity over the past year has been moderate as demand has continued to slip. Price settlements of market price contracts, which are indicative of the current market for uranium, have declined in real terms since January 1978 and absolute terms since the beginning of this year. U.S. uranium producers

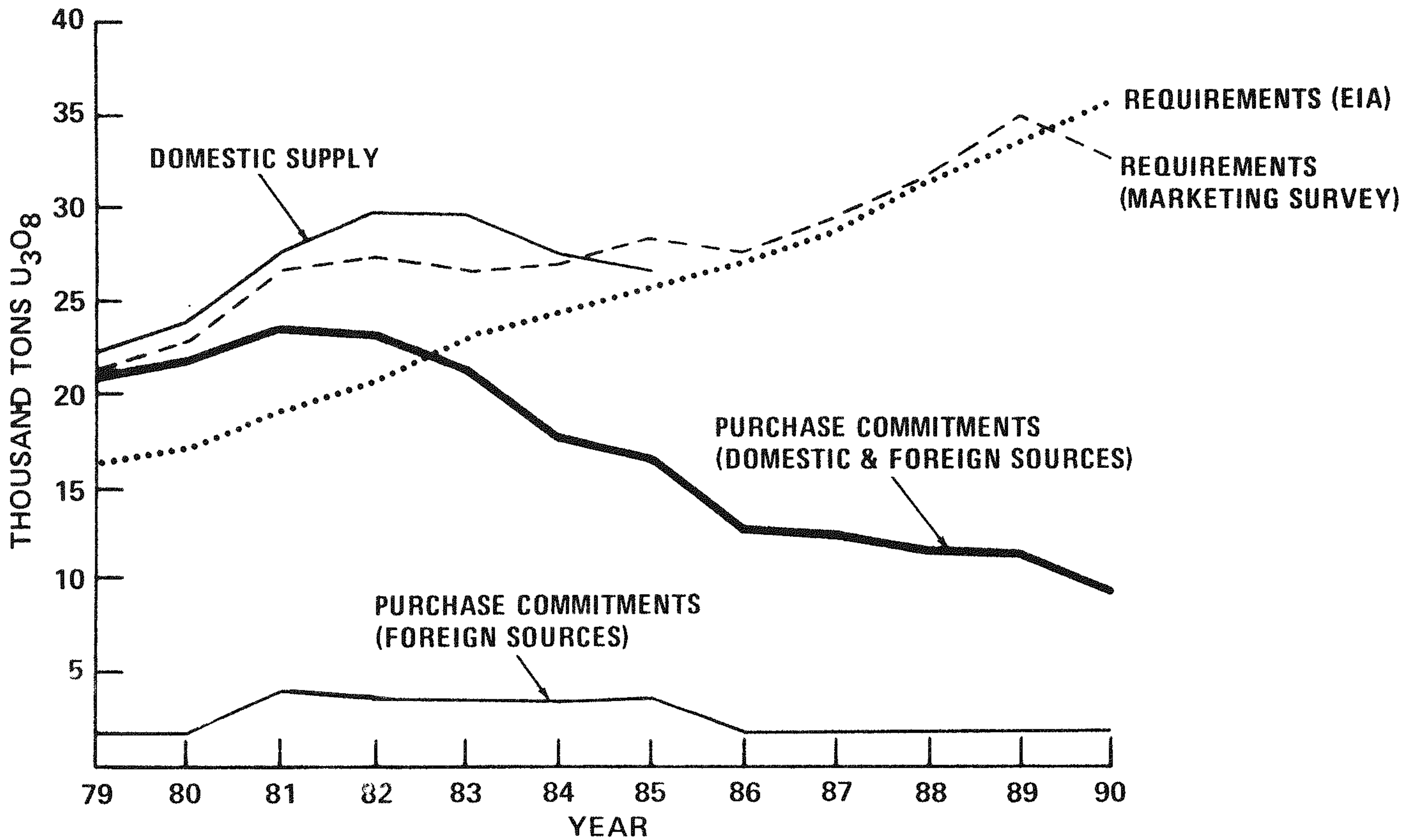

FIGURE 5. *Domestic uranium supply vs. requirements*

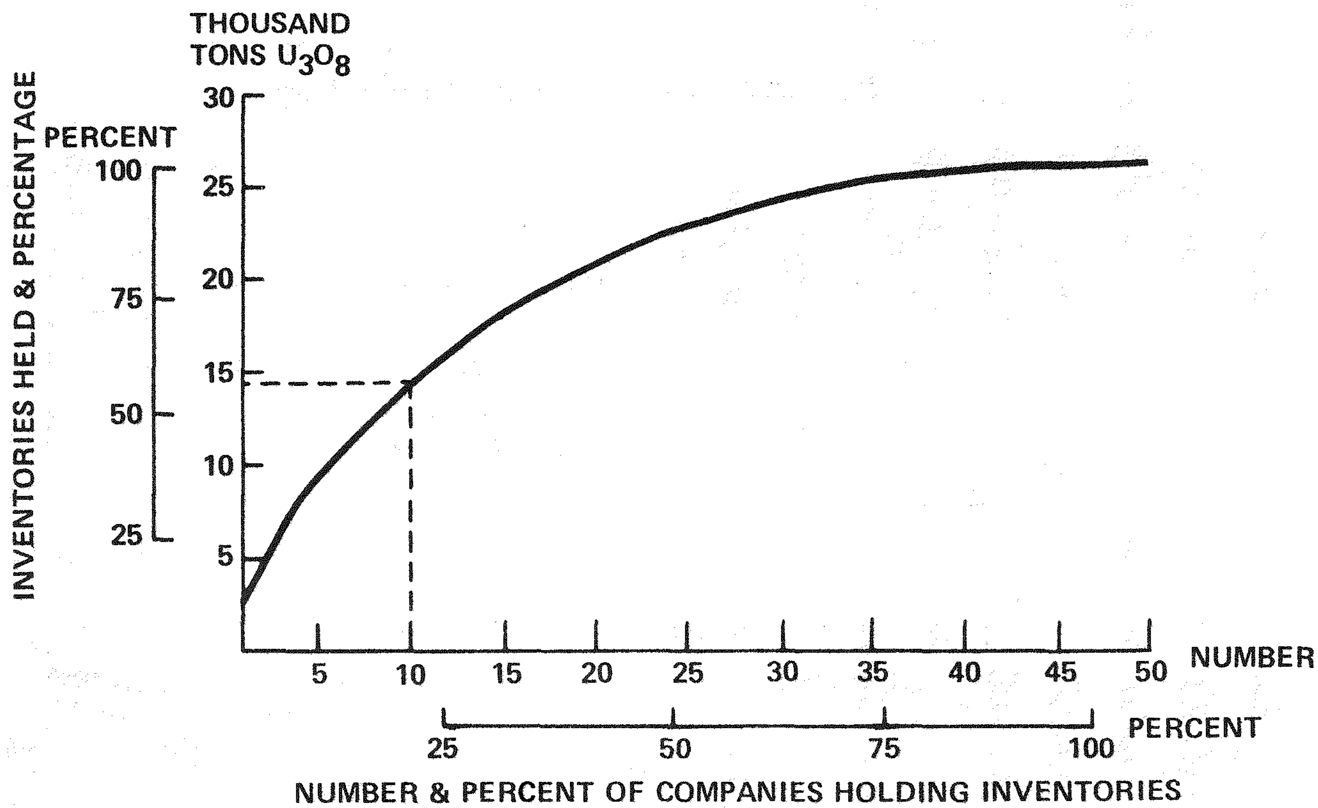

FIGURE 6. *Distribution of U.S. utility inventories domestic and foreign normal uranium: January 1, 1979*

TABLE 15. *Utility views on uranium inventories*

Desired Inventory, Year's Needs		Present Inventory Levels: Less Than Desirable	About Right	Excessive	Did Not State	Total
	0	0	0	1	0	1
	>0–1	2	6	4	3	15
	>1–2	1	2	1	1	5
	Did not State	2	12	4	–	18
	Total	5	20	10	4	39*

*10 additional utilities indicated they had no formal policy.

have responded to this reduction in demand and falling prices by cutting back on their expansion plans.

Forward uranium import commitments exceed forward export commitments, but more new export commitments than import commitments have been made during the 1975 to 1978 period. As constructed from marketing survey data, U.S. supply exceeds U.S. demand up to the mid-1980s. The level of inventories held by utilities and other buyers is substantial and, given the supply and demand relationship, could continue to increase. To date, utilities have not been very active as suppliers in the market.

URANIUM MARKET FORECAST

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October 1979

INTRODUCTION

A proper admonition about any forecasting effort might well be that "there are no facts about the future." While this statement is certainly true, it might be worthwhile to elaborate on its scope. For example, the evolution of nuclear power starkly illustrates not only are we uncertain about the course of future events, but we are not even able to grasp the array of possible paths for these future events. The accident sequence at Three Mile Island (TMI) developed in a manner not unforeseen by nuclear safety experts, but it is doubtful that these experts (or we novices) had sufficient appreciation of the tendency for errors to compound throughout the events of March 28, 1979.

Furthermore, the technical consequences of the accident at TMI are dwarfed by the social and institutional impacts. The accident has brought to the forefront such issues as the proper roles of equity holders versus stockholders in assuming the cost of replacement power due to extended plant outages and the adequacy of private and public financial compensation. Even the Nuclear Regulatory Commission (NRC) may not survive in its present form if we are to believe the intimations of several Kemeny Commission (the President's Special Commission on TMI) members.

The point of all this discussion is to underscore what has become by now a fact of life for the nuclear industry. Uncertainty about the future has become a double-edged sword, and the industry has been feeling the blows from both edges. One edge is the continuing lack of resolution of issues at the heart of nuclear power—issues such as the ultimate disposition of radioactive nuclear waste. The other edge is the introduction (or resurfacing) of new issues, such as those prompted by TMI and the Carter Administration's nonproliferation policies.

The objective of this report is to contribute as much as possible to an understanding of how events in the past year have affected the outlook for nuclear power growth and, by implication, the future of the uranium market. In order to lend perspective to this report, it might be useful to outline briefly the functions of the Energy Information Administration (EIA) as it is popularly called. EIA was explicitly established in the U.S. Department of Energy's (DOE) authorizing legislation as the branch of DOE responsible for essential energy data collection and analysis activities. Congressional intent in establishing EIA was to maintain a separation between what are considered basically data collection and analysis activities on the one hand and policy formulation and advocacy activities on the other hand. Furthermore, the DOE Act gives the EIA Administrator the authority to publish any statistical or analytical report without requiring prior approval from any other DOE officials. There is a price for this independence, however; EIA is not allowed to engage directly in any energy policy design or advocacy activites. EIA does perform energy policy analysis, but this analysis is done at the request of other parts of DOE or the Congress, and any other policies to be analyzed are specified by the requesting client.

EIA is required by its authorizing legislation to submit an annual report to the Congress—a report which documents its activities for the previous year, presents historical data series on energy market activity, and projects energy market activities into the future, "under various sets of conditions." EIA resolves the policy advocacy dilemma in its independent projections of energy markets by considering only those laws and regulations that are in force at the time of the analysis. However, these independent projections do consider variations in nonpolicy parameters, such as geologic endowment of energy resources or the level of national economic activity.

EIA's forecast report to Congress (Volume Three of its Annual Report) was released in July 1979 (Energy Information Administration, 1979), although most of the analysis was completed by the end of February 1979. In general, these latest forecast results update those of a year earlier, published as EIA's first report to Congress (Energy Information Administration, 1978). Some important differences in their respective assumptions and results are summarized in figure 1. Within the context of the "current law and regulation" constraint, variations were made in gross sets of input assumptions, as shown in figure 2, in an attempt to bracket the range of most probable energy futures. The Scenarios A through E in figure 2 combine various permutations of three domestic "demand" curves (low, medium, and high economic activity), three domestic "supply" curves (low, medium, and high availability at a given price), and three levels of world oil prices. The Projection Series C, which incorporates the medium demand, supply, and world oil price assumptions, is usually the point of reference although one should not associate the term "most probable" with the Series C results. The Projection Series A and E result in the extremes of energy quantities, whereas Series B and D exhibit the widest coverage of energy prices, as illustrated in figure 3.

Assumptions

1. World oil price levels are explicitly modeled in ARC 1978, rather than assumed as in ARC 1977.
2. New engineering/process demand models are used for ARC 1978, rather than pure econometric demand models of ARC 1977.
3. Underlying data base is updated to include such things as nuclear cancellations and the new United Mine Workers contract.
4. Policy assumptions are updated to reflect the National Energy Act legislation .

Results

1. World oil price levels are considerably higher in ARC 1978 than ARC 1977.
2. Total demand for energy is lower in ARC 1978 although electricity demand levels are comparable to ARC 1977.
3. Post-1985 nuclear power projections are diminished.

FIGURE 1. *Comparison of EIA's 1977 and 1978 Annual Reports to Congress (ARC)*

In retrospect, it would appear that the Series E assumptions are most consistent with such factors as the oil supply disruption in Iran which was not incorporated into the analysis, the present path of world economic activity, and the accident at TMI which also was not explicitly factored into the analysis.

NUCLEAR POWER GROWTH

Methodology

While the methodology used by EIA for projecting nuclear power for both the domestic and foreign regions is presented in the EIA Annual Report for 1978, let us briefly restate some important principles. In summary, the analysis begins with the assembling of data on the current status of each known nuclear reactor project. These data consist of such items as reported construction completion, current and projected licensing activities, and measures of the "momentum" of each project. The measure of momentum incorporates such things as recent progress, or lack thereof, in licensing or construction, as evidenced by increases in the reported percent completion of construction or by recent announcements of delays.

Once this "snapshot" of each project's current status has been made, then institutional factors are introduced where appropriate, to determine the approximate relative priorities for completion of these projects. For example, all projects of one utility company generally have a preferred sequence of startup, as indicated by the utility's announced plans. Also, relative priorities can be determined in geographical regions for which there is a great deal of joint ownership of the individual projects. The preference ranking of individual projects, coupled with their most recent or pending activites and with empirically determined estimates of the required time durations for the licensing and construction tasks, is used to generate estimates of startup dates for each project. Thus, each startup date reflects the various technical and institutional constraints on nuclear power construction in general, especially since a

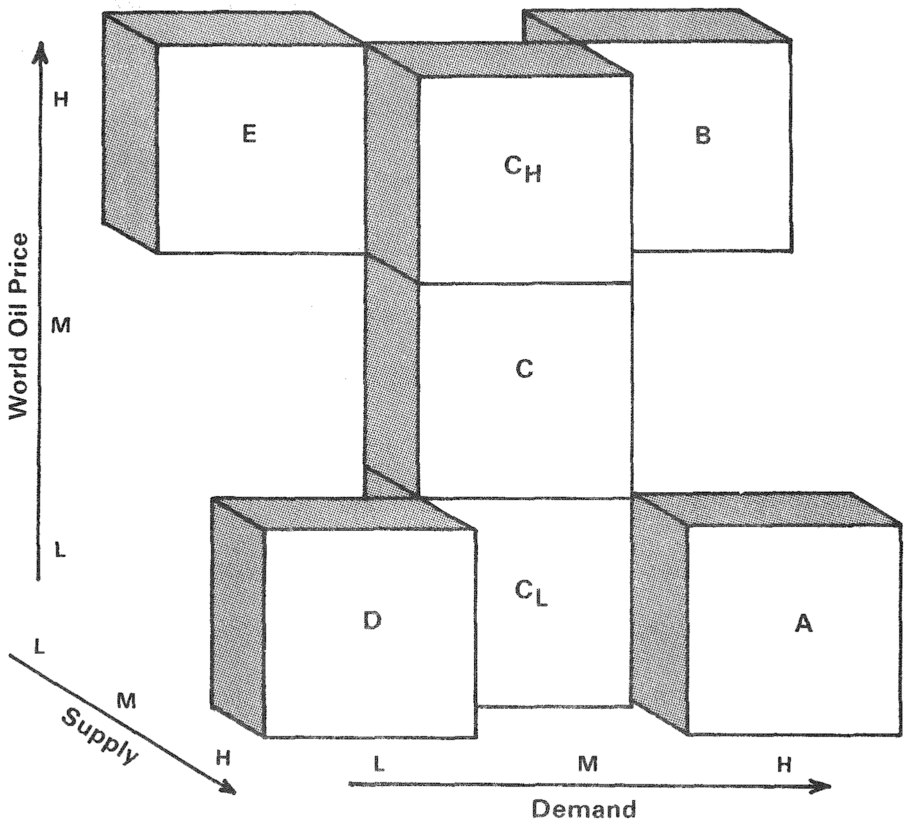

FIGURE 2. *EIA projection series for the 1978 Annual Report to Congress (ARC)*

great deal of effort is spent on those projects closest to completion for which particular problems or progress can be identified. If delays are indicated for these lead projects, many times these delays must be propagated to the schedules for trailing projects.

Two further factors must be introduced—financial constraints and the demand for new generating capacity on the National electricity grid. The former category can be handled by computing the utility's generating-unit construction expenditure stream including, of course, planned fossil or hydroelectric projects, and comparing this projected expenditures stream with the utility's recent history. In those cases for which large increases in construction expenditures are indicated and for which the utility would likely have difficulty raising the scheduled capital, the construction schedule is adjusted (slipped) to ameliorate the projected financial strain.

The demand for power is introduced at the last stage of the analysis. The costs for supplying nuclear energy are estimated as a function of the quantity to be supplied. The "supply curves" so estimated, along with analogous ones for the other energy sources, are incorporated into large energy/economic models. These models equilibrate supply and demand quantities by determining the most efficient set of energy prices to clear the market.

Because of the long-lead times for nuclear power planning, deployment of the current inventory of nuclear power projects sets an upper limit on the amount of nuclear power capacity available for the future—at least through the year 1990. The nuclear supply curves described previously include these restrictions. Beyond the year 1990, there remains the possibility that yet unknown nuclear generating units could be ordered and brought online. Of course, there remains the determination of the conditions under which these orders would occur, as discussed below. For the long-term period, the EIA analysis assumes the removal, or at least the advent of predictability, of major institutional constraints on nuclear energy supplies, so that the growth of nuclear power is assumed to reflect only the projected demand for

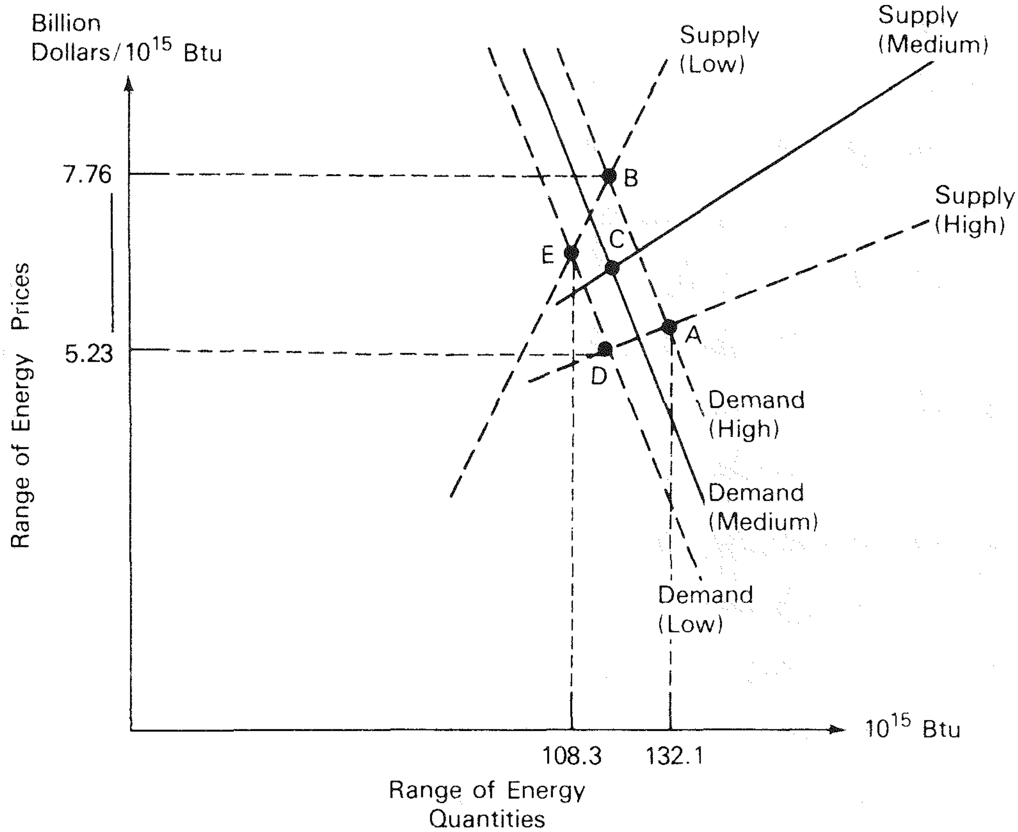

FIGURE 3. *The projection series: quantities for 1995*

baseload electrical generating capacity and the projected cost of nuclear power relative to other types of energy sources.

Results for Domestic Nuclear Power

The results for the domestic "Series C" (mid-case) projection, as published in the EIA Annual Report for 1978, are shown in table 1. In general, the Series C results point to a future "electrical world." Electricity is projected to grow at a rate double to the growth rate of total energy. Futhermore, nuclear power continues to grow at a rate that approximately doubles that of electricity, albeit from a relatively lower base. In absolute terms, about 8.5 gigawatts (GWe) of nuclear power capacity would be added on an average year between 1978 and 1990, rising to about 10 GWe per year in the following decade and then doubling to about 20 GWe per year for the first two decades of the 21st Century.

The growth of electricity and nuclear power is further illustrated in figure 4. Nuclear power and coal contribute about equal shares to electricity growth through the end of the 20th Century. But in the 21st Century, nuclear power carries the entire burden for electricity growth because of the increasing demand for coal both in the industrial sector and as feedstock for synthetic fuel production and because of the projected cost advantages of nuclear power for electricity production. If relatively low-cost uranium supplies are not forthcoming or if nuclear power construction costs increase faster than coal-fired construction costs, in contrast to the assumptions of Series C, then part of the nuclear growth after the year 2000 could be displaced by coal-fired generation. Thus, a great deal of caution is advised when considering the nuclear aspects of this long-term projection. Nuclear power growth is spurred by a combination of the indicated high degree of electrification and the cost advantage projected for nuclear power, primarily due to the assumed abundance of low-cost uranium resources. Thus, it is unlikely that higher levels of nuclear power could be realized for this set of energy and economic assumptions although one could easily postulate conditions leading to lower levels of nuclear power use in the long term.

TABLE 1. *EIA domestic projection "Series C"*

Activity*	Activity Level for Year					Average Annual Growth Rate (%)			
	1977	1985	1990	1995	2020	1977-1985	1985-1990	1990-1995	1995-2020
Real GNP (trillion dollars)	2.02	2.70	3.15	3.64	6.60	3.7	3.0	2.9	2.4
World crude oil price (dollars per barrel)	15.00	15.00	18.50	23.50	30.00	0	4.3	5.0	**
End Use Energy Consumption (Quads)	60.5	68	74	83	104	1.3	2.0	2.2	0.9
Primary Energy Supply (Quads)	79.8	92	104	117	169	1.8	2.5	2.5	1.5
Total Electricity Production (Billion kwh)	2,125	3,050	3,710	4,450	8,120	4.6	4.0	3.7	2.4
Percent of Electricity from Nuclear	11.8	19	22	25	49	-	-	-	-
Installed Nuclear Power Capacity (GWe)	47	114	152	208	670	11.7	5.9	6.5	4.8

* All monetary figures are in constant (1978) dollars
** Rises to 30 dollars per barrel in the year 2000, and remains constant thereafter in constant (1978) dollars

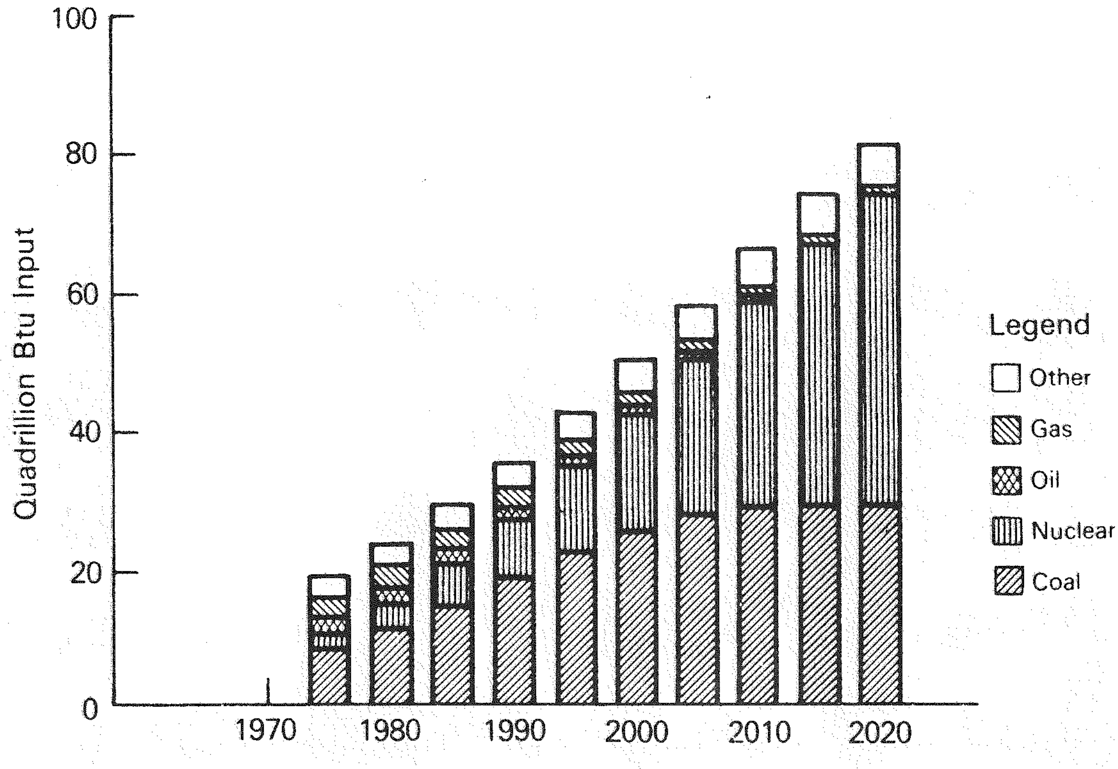

FIGURE 4. *Coal and nuclear power dominate electricity generation*

Unfortunately, time constraints and the relative infancy of EIA's long-term analysis program did not allow the development of a full array of projection series as was done for the midterm. Thus, the consequences of various assumptions about such things as the cost and size of the domestic uranium resource base, regional siting constraints, etc., were not investigated. Alternative scenarios were developed for the midterm period—scenarios designed to test the sensitivity of the energy/quantity results to various supply and demand assumptions. These were addressed in the previous section and the Projection Series A through E in figure 2.

The low-nuclear energy supply assumptions used for the Series B and E reflect more pessimistic construction and licensing schedules and continuing cancellations and deferrals of nuclear power projects. The high nuclear supply assumptions, Series A and D, reflect more optimistic considerations for nuclear power, including a resumption of nuclear plant ordering. Very little adjustment was required to accommodate variations in the demand assumptions of figure 2. There is projected to be an ample demand for nuclear generating capacity, at least in the "demand for power" sense.

The resulting range of domestic nuclear power forecasted for the midterm is shown in table 2. Also shown are the results of various other studies, including EIA's previous report to Congress for 1977. The EIA results for nuclear power capacity in 1985 are essentially the same for both Annual Reports. For the year 1990, the range has slipped downward in the past year. There are various reasons for this slippage. The estimates for the technical limits of construction and licensing time did not change appreciably even though the supporting data for making the estimates were updated by a year. Two other factors are important, however. The first is the many projects that appeared to have institutional momentum in 1977 but did not maintain momentum during 1978. Examples are the projects in the State of New York and several others for which the NRC reported anticipated license applications. The second factor is the evaporation of the construction momentum for numerous projects, especially the second or successive units at

TABLE 2. *Midterm domestic nuclear power capacity in commercial operation, comparison of forecasts, 1985–1995 (GWe)*

Source	1985	1990	1995
1978 Annual Report	102-118	142-171	186-225
1977 Annual Report	100-122	157-192	—
DOE Utility Survey (January 1979)	139	181	—
U.S. NRC (September 1978)	113	—	—
U.S. Department of Commerce (November 1978)	141	—	—
Data Resources, Inc. (April 1979)	116	147	205
National Electric Reliability Council (August 1978)	138	—	—
Electrical World Magazine Survey (January 1979)	137	170	—
Westinghouse Corporation (December 1978)	111	173	246
Babcock and Wilcox Co. (March 1979)	123	165	200

some sites for which construction activity was reported during 1977 but not maintained during 1978.

Comparison of the EIA projections with other sources, especially for the year 1985, indicates that studies based primarily on surveys of the electric utility industry yield much higher nuclear growth estimates than those obtained from other sources. The difference between utility announcements and independent projections is probably that the independent projections reflect average experienced lead times, whereas the utility estimates are really planning targets, in most cases.

Results For Foreign Nuclear Power

Foreign nuclear power forecasts through 1995 are also prepared as part of EIA's normal analysis activities. The techniques used are analogous to those used for domestic nuclear projections although the supporting data base on foreign nuclear power programs is not as extensive as that for the domestic programs.

The latest EIA estimates of foreign nuclear power capacities are shown in table 3. In many instances, broad numerical ranges are given that reflect the large uncertainties associated with many national programs, particularly the issues of rising construction costs, reactor safety, and radioactive waste management which are no longer exclusive to the domestic program and public debate. In the nations of the Organization for Economic Cooperation and Development (OECD), growth in electricity demand has generally declined in recent years, and as a result, official program delays have been frequent. In unusual cases, public referenda have been exercised to determine nuclear policy. Although most Asian and European nuclear programs are affected by these political, economic, and environmental uncertainties, nuclear power is projected to increase significantly its contribution to energy supplies during the midterm. Because of reduced growth rates in projected electricity demand, the nuclear capacities forecasted for most countries in Projection Series A through E are toward the lower end of the ranges of potential capacity given in table 3. However, the EIA forecasts indicate that nuclear power will provide between 26 and 30 percent of the foreign OECD's electricity in 1995, compared to 8 percent in 1976. Led by an ambitious French light-water

TABLE 3. *Foreign nuclear generating capacity: actual and potential, 1978-1995*[a]

	1978	1985	1990	1995
OECD[b]				
Australia/N.Z.	—	—	—	0–1.0
Austria/Switz	1.0	1.9–2.6	2.9–3.8	3.8–4.9
Benelux/Denmark	2.3	5.0–6.0	6.0–6.9	8.2–9.6
Canada	4.8	9.8–10.3	14.2–16.2	17.2–22.1
France	6.5	24.4–28.2	35.8–41.8	48.3–54.5
Germany	9.1	15.9–18.4	20.1–28.1	28.1–36.7
Greece/Turkey	—	—	—	0.6–1.8
Italy	0.6	1.4	3.4–6.4	6.4–10.4
Japan	10.9	16.9–19.7	26.8–32.7	41.4–50.0
Scandinavia	5.9	9.5	9.5–12.7	12.7–15.8
Spain/Portugal	1.1	5.8–7.4	8.3–11.2	10.8–15.2
U.K./Ireland	5.9	9.3	12.4	18.3–20.7
Subtotal	48.1	100–113	139–172	196–243
Non-OECD				
Argentina	0.3	0.9	2.1–2.7	3.3–4.5
Brazil	—	1.8	1.8–3.1	3.1–5.7
India	1.0	1.2–1.5	1.9–2.2	2.9–3.3
South Korea	0.6	1.8–2.7	5.5–7.4	9.3–13.5
Iran	—	1.2–2.4	2.4	2.4–3.6
Mexico	—	1.3	1.9–2.6	2.6–4.1
Pakistan	0.1	0.1	0.1–0.7	0.7–1.9
Philippines	—	0.6	0.6	0.6–1.8
South Africa	—	0.9	1.8–3.6	3.6–5.4
Taiwan	0.6	3.1–4.0	4.9–6.7	6.7–8.7
Yugoslavia	—	0.6	0.6–1.2	1.2–1.8
Subtotal	2.6	14–16	24–33	36–54
Total OECD and Non-OECD	50.7	114–129	163–205	232–297

[a]Gigawatts of capacity in commercial operation at the end of each forecast year.

[b]National and regional groupings as modeled in the EIA International Energy Evaluation System (IEES).

reactor (LWR) program, European utilization of nuclear energy is forecasted to be even greater, rising to between 34 and 40 percent of total European electricity production by 1995.

More modest nuclear programs are anticipated for most non-OECD developing nations. Several ambitious nuclear power program targets have been reduced to more modest levels during the last year. The defacto demise and decline of the Iranian and Brazilian programs, for example, are now well publicized. Currently, a limited number of non-OECD nuclear plants are under construction, and poor nations are particularly hard pressed to finance nuclear projects in the face of rising oil prices and social and agricultural programs which have higher priorities. While programs evolving in South Korea and Taiwan could be quite significant in the future, EIA forecasts that nuclear power will more generally contribute only on the order of 10 to 15 percent of the total electricity generated in the non-OECD countries by 1995.

Comparison of Forecasts for WOCA

Aggregate forecasts for the World Outside Communist Areas (WOCA) are illustrated in table 4. Compared to EIA forecasts presented in the 1977 Annual Report, the current forecasts through the year 2000 represent about a 20-percent reduction in nuclear capacity in 1995 and nearly a 30-percent reduction for the year 2000. Compared to the final forecasts ranges provided by the International Nuclear Fuel Cycle Evaluation (INFCE), the current EIA forecasts imply an even greater reduction, between 24 to 32 percent by 1995 and 35 to 38 percent by the year 2000. Because they are highly motivated by political goals, the INFCE forecasts for the post-1990 period were recognized as very optimistic; they portended a near trebling of capacity in 10 years. The current EIA forecasts in and of themselves imply a doubling of capacity during the same period, but, as previously described, are evaluated in a much more rigorous analytical framework than was possible during the INFCE exercise.

URANIUM REQUIREMENTS

From nuclear power forecasts, it is possible to derive the associated natural uranium requirements. Since a variation in the installed nuclear capacity is only one of several possible sources of variation in fuel requirements, the initial focus will be on a "reference case" for fuel requirements—a case not necessarily considered the most probable but a case which does provide a convenient point of reference for later discussion. Following discussion of the "reference case," attention will be focused on uncertainties in the input parameters and the corresponding sensitivity of the fuel requirements to these uncertainties.

A point of caution is imperative at this point. The nuclear fuel requirements presented here have precise meaning—they are the physical quantities minimally required to maintain the assumed nuclear power programs. These requirements are not meant to be synonymous with "market demand" for fuel—a demand which would additionally reflect procurement and inventory practices of buyers and sellers and the degree of buyer foresight.

Reference Uranium Requirements

The basic assumptions for the "reference case" are shown in table 5. These assumptions are addressed elsewhere (Clark and Reynolds, 1978) but are summarized here:

1. The EIA midcase nuclear growth forecast is discussed earlier as the "Series C" estimate from the EIA's 1978 Annual Report. Only light-water reactors are considered for the United States, whereas the assumed foreign reactor mix reflects the same weightings as the INFCE nuclear power forecasts.

2. The power plant capacity factor (ratio of actual electrical output to maximum design capability) is represented by a profile which begins at 40 percent during 6 months of initial operation followed by a plateau at 65 percent until the 15th year of operation. Between the 15th and 30th (last) year of operation, the capacity factor declines by 2 percentage points per year but never falls below 40 percent. This startup and the 65-percent plateau roughly approximates the historical pattern of performance for light-water reactors.

TABLE 4. *Nuclear power forecasts (GWe) for World Outside Communist Areas (WOCA)*

SOURCE	1985	1990	1995	2000
INFCE	245-274	373-462	550-770	850-1200
EIA 1977 Annual Report				
U.S.	100-122	157-192	200-275	255-395
Other WOCA	123-140	193-238	315-375	515-655
Total WOCA	223-262	350-430	515-650	770-1050
EIA 1978 Annual Report				
U.S.	102-118	142-171	186-225	235-300
Other WOCA	114-129	163-205	232-297	315-450
Total WOCA	216-247	305-376	418-522	550-750

TABLE 5. *Uranium requirements "for reference case" parameters*

Parameter Description	Parameter Value: Domestic	Parameter Value: Foreign
Nuclear power growth	EIA mid case	EIA mid case
Reactor mix	LWR	INFCE weightings
Power plant capacity factor	65% plateau (57% lifetime average)	
Fuel utilization efficiency	Past industry experience	
Recycle option	No reprocessing	Planned reprocessing
Enrichment plant tails assay	0.20%	0.20%

3. The fuel utilization efficiency, obtained from historical LWR performance, is a combination of expected heat production in the fuel elements and the nuclear plant thermal efficiency. These efficiency parameters are discussed, in more detail, in a previous presentation (Clark and Reynolds, 1978), where they are described as the "empirical" fuel-cycle plans.

4. Reprocessing and recycling of uranium and plutonium in LWR's is assumed to be deferred beyond the year 2020 for domestic nuclear power plants. Outside the United States, the schedule of available reprocessing capacity reflects currently known plans.

5. All enrichment contracts are assumed to be serviced at 0.20-percent ^{235}U tails assay.

The resulting reference uranium requirements are shown in figure 5 for both the foreign and domestic cases through 1995. In addition, the long-term domestic outlook is addressed in figure 6. In the midterm reference case (figure 5), domestic uranium requirements generally match or slightly exceed the foreign requirements until the end of the period. The assumed use of plutonium and uranium recycle just offsets the greater foreign nuclear power capacity in producing this balance of foreign and domestic requirements for uranium.

The domestic long-term reference case, labeled EIA "Series C" Current Once-through Cycle in figure 6, exhibits a sharply increasing trend after the year 2000—a reflection of the "Series C" long-term growth of nuclear power. The reference case requirements increase from about 55,000 short tons in the year 2000 to about 128,000 short tons in the year 2020. The curve in figure 6 labeled "Firm" Nuclear Power Capacity shows the requirements for the 118 GWe of "firm" domestic nuclear power capacity that is currently either in operation or well into construction. By inference, the uranium requirements above this line are contingent on favorable decisions for the installation of additional nuclear power capacity beyond the relatively assured 118 GWe. The third line of figure 6 will be discussed in the next section.

Uncertainties and Sensitivities of Uranium Requirements Forecasts

As mentioned earlier, there are several sources of uncertainty in the derivation of uranium requirements. Figure 7 shows the uncertain factors and the sensitivities of the uranium requirements to individual variations in the factors for the 1990 and 1995 domestic reference case. Also shown are the sensitivities of the corresponding enrichment and spent-fuel storage requirements. The fuel requirements sensitivities in figure 7 are shown as percentages of the reference case. This presentation mode enables the simple estimation of the impact of combined uncertainties through multiplication of the individual impacts.

Both domestic and foreign fuel utilization efficiencies have two uncertain factors that would tend to decrease the fuel requirements. The first improvement factor would result if the industry were to achieve its current design parameter values for fuel burnup and plant thermal efficiencies on an industry-average basis. Another independent improvement factor reflects the introduction of a hypothetically improved once-through LWR fuel cycle design beginning around 1990 and fully implemented by the year 2000.

The enrichment plant tails assay uncertainty reflects the following considerations. We feel that 0.20 percent is probably a reasonable lower

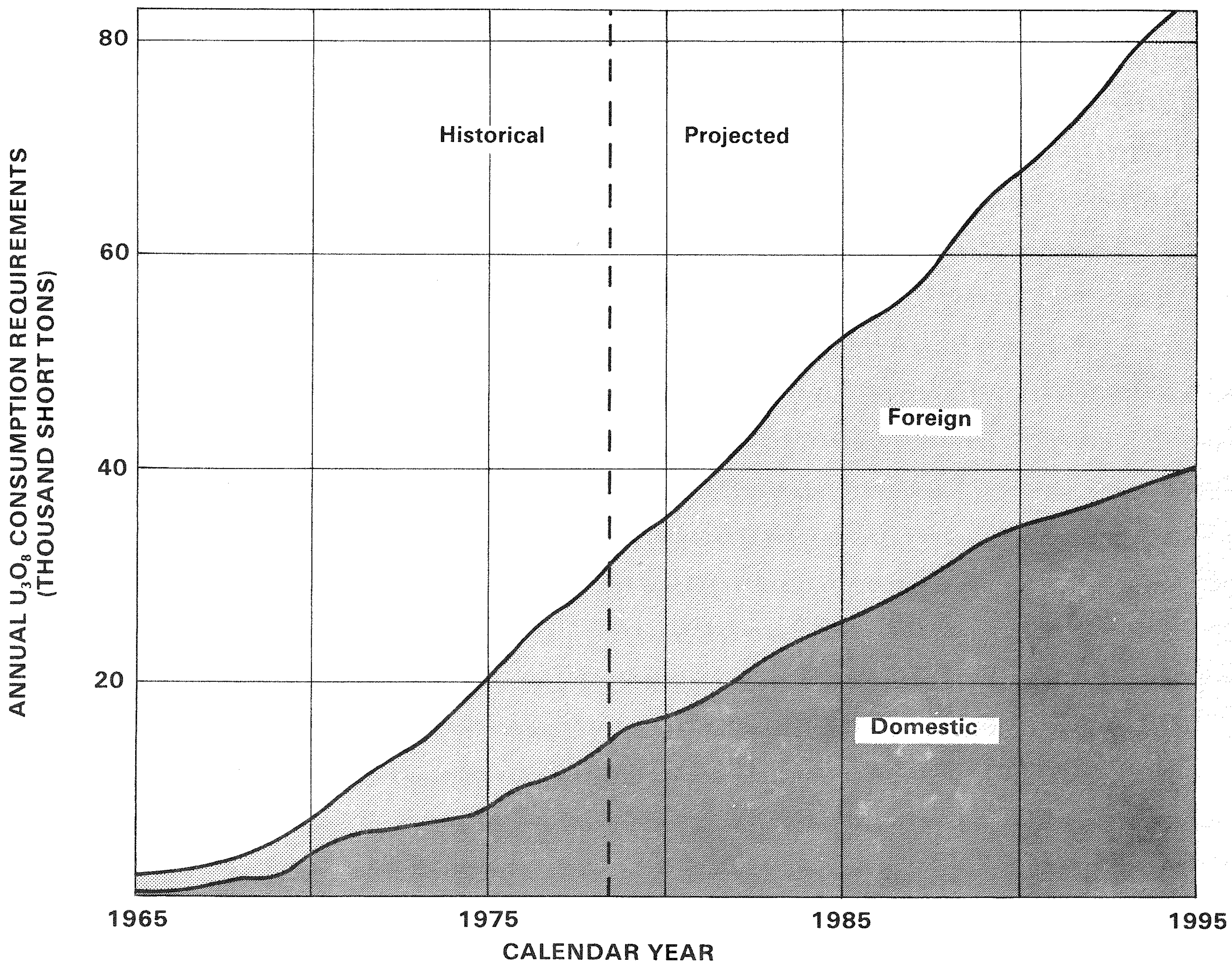

FIGURE 5. *Domestic and foreign uranium consumption history and EIA "Series C" 1965–1995*

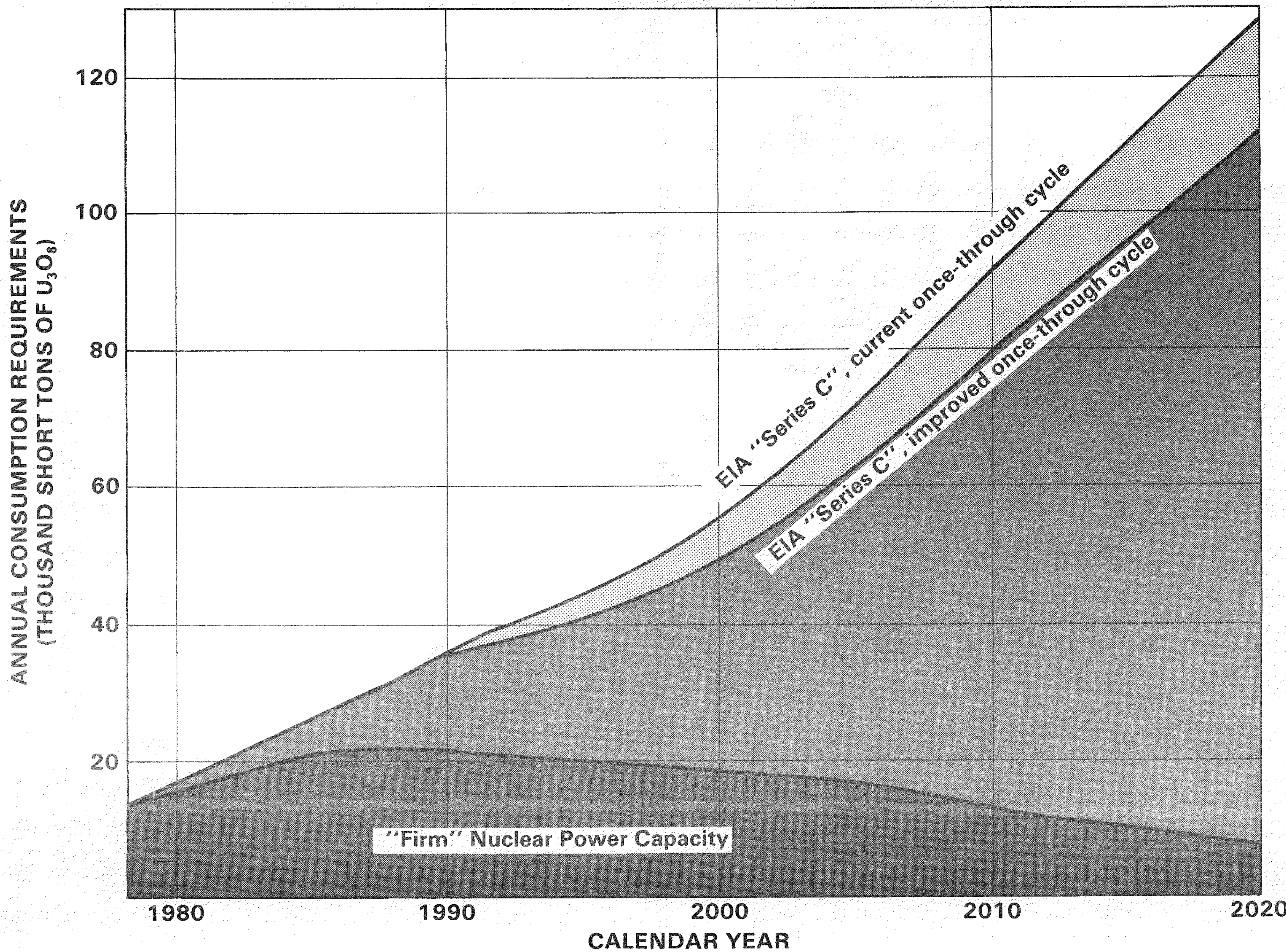

FIGURE 6. *Projected long-term domestic U_3O_8 consumption*

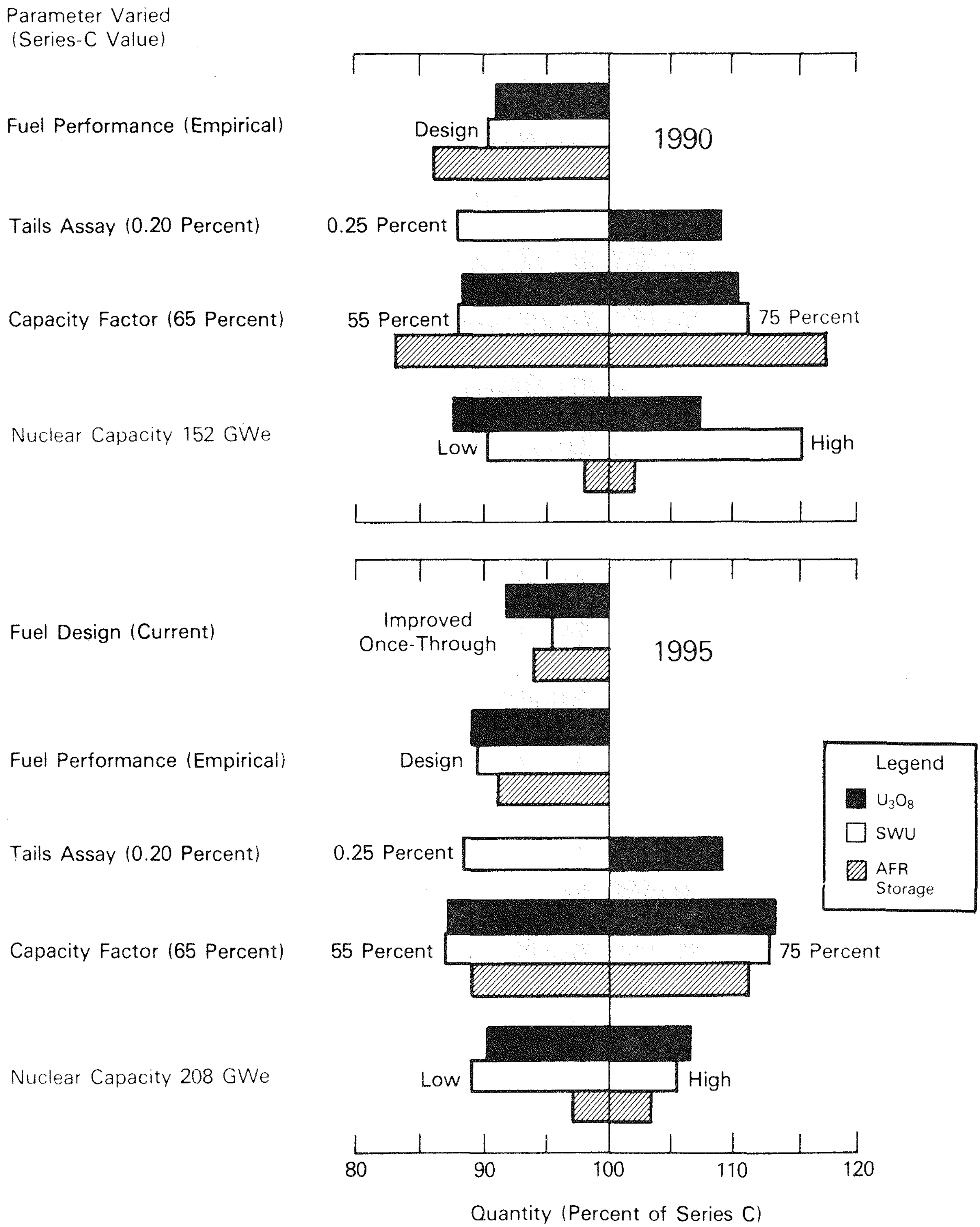

FIGURE 7. *Sensitivities of enrichment (SWU), Uranium (U_3O_8), and away-from-reactor (AFR) spent-fuel storage requirements: "Series C," 1990-1995*

bound, especially since the bulk of DOE's enrichment capacity will still be gaseous diffusion technology well beyond 1990. For an upper bound, the value of 0.25 percent is consistent with DOE's announced intentions.

Possibly the most difficult uncertain area is the uranium and plutonium recycle. Domestically, reprocessing and recycling are an area of policy consideration. Obviously, current domestic policy precludes reprocessing for an indefinite period. Foreign LWR reprocessing is open to consideration since there are operating and planned facilities. The present analysis considers no range for domestic reprocessing and recycling but does consider a lower bound reflecting no reprocessing and a higher bound reflecting planned reprocessing capability by the year 2000 for the foreign case. The absence of recycle in the foreign case increases uranium requirements by about 25 percent for both 1990 and 1995.

The variation range for the average nuclear plant capacity factor reflects a 10-percent point-swing of the plateau about the reference value of 65 percent.

Finally, the nuclear capacity growth sensitivities reflect a displacement to the low- and high-nuclear capacities of the EIA 1978 Annual Report.

URANIUM MARKET STUDIES

Part of the mandated activities of EIA involve studies of the markets for fuels under various conditions. In the case of uranium, the major analysis tool for such study, including that reported in EIA Annual Report for 1978, utilizes the methodology developed by Dr. Don R. deHalas and embodied by his "EUREKA" uranium market model.

Methodology

The methodology is basically a simulation of uranium-producer-investment-decision behavior coupled with purchasing decisions on the part of uranium consumers. This methodology, in its present state, is confined to the domestic market, with allowances for imports and exports although a major development effort is underway to produce a world-market-level capability. As figure 8 indicates, the methodology encompasses market activities in the consummation of uranium supply contracts and investment activities in both exploration and production capacity with special emphasis on the decision processes involved in successive years.

In the methodology's present application, the future demand for uranium is an exogenous input unrelated to price. Supply contracts made for uranium in a given year are based on the buyers'

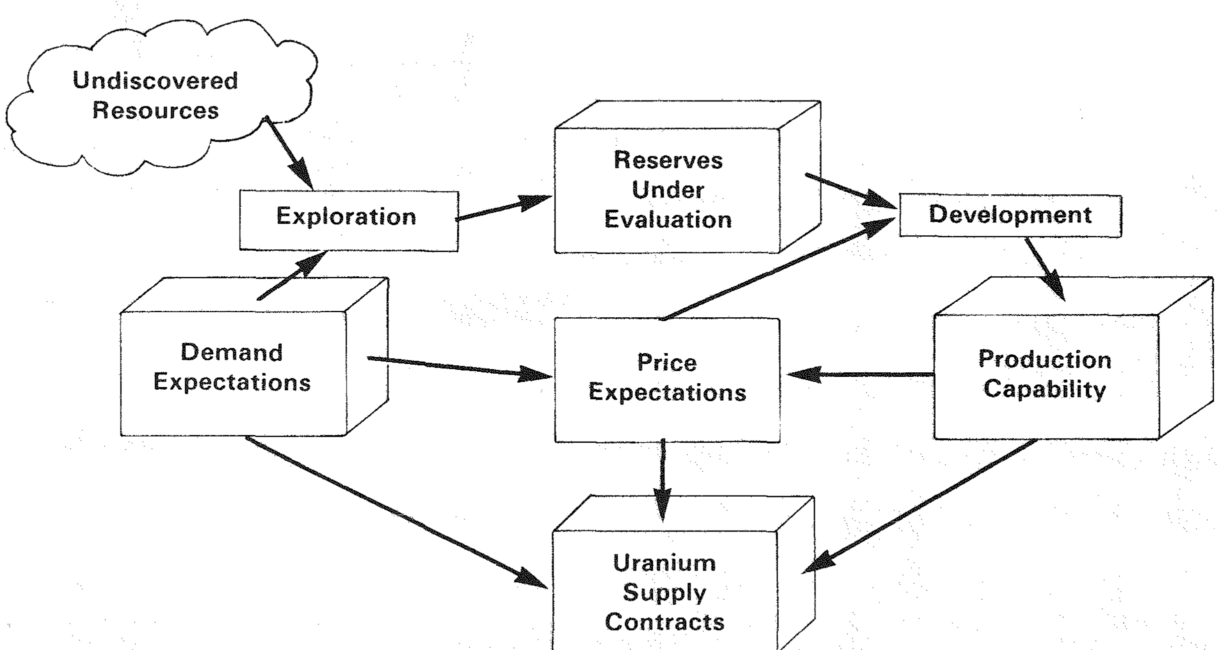

FIGURE 8. *Uranium market analysis methodology*

forward-looking expectations for uranium requirements. These expectations can be dynamic because they can evolve in a predetermined manner with the simulation of time. A record is maintained of supply arrangements, as they are forecasted, beginning with contracts in place at the start of the analysis period. Of course, commitments can be made only where sufficient production capability can be brought on stream although allowances can be made for drawing down consumer inventories or importing up to a specified level if domestic production capacity is not adequate to meet demand in a given year.

The base price for new contracts signed in a year of the simulation, or for the settlement of previously signed market-price contracts, is started at a given level and then adjusted each year to reflect the ratio of uncommitted production capacity to demand without supply contracts over a specified forward time span.

Concurrently to the market transactions in a given year, uranium producers are making investment decisions that respond to their expectations of future price and demand and to their current revenues. For example, exploration activities are carried out in a given year at a level determined by the expected demand in a future time window, and the amount of exploration expenditures is somewhat constrained by the availability of profits from industry revenues. In a shorter time frame, reserves that have been identified by exploration activites are evaluated on the basis of expected production costs and profit requirements against the then-current trend of the market price.

Those properties, favorably evaluated, are partially developed during the year being currently simulated. Furthermore, properties requiring development are reevaluated each year on the basis of any new trends in the market price and on the basis of current forward costs. Development activities may be halted during periods in which the market price trend is not favorable.

As developed properties come into production, this additional supply contributes to the supply/demand ratio and, thus, to the pressure on the market price to respond appropriately.

Reference Case and Sensitivities

The domestic requirements discussed above as the EIA "reference case" were specified as the "EUREKA" methodology demand after the adjustment of the constraining effects of the enrichment contract feed-delivery schedules. Such modifications were made by assuming that current enrichment contracts would be adjusted gradually to cumulatively match forecasted requirements by the year 1990. This adjusted quantity schedule and the price trajectories resulting from the market analysis are shown in figure 9. The band of prices shown in the figure reflect the sensitivity to a wide range of variation in the assumptions for behavioral parameters in the analysis framework. Such behavioral parameters include the producers' required rate of return on equity, the risk premium for uranium investment, the degree of buyer inventory mobility, and the relative market shares for fixed-price/market-price contracts and captive production.

As seen from the top half of figure 9, both the base price for new contracts and the average for deliveries increase substantially in real terms over the midterm period for the reference assumptions.

The reference values of some key parameters and the sensitivity of the new contract market price for 1985 and 1995 are shown in figure 10. The 1985 market price is sensitive to the market psychology (behavioral) parameters and to the demand level, whereas for the year 1995, the mine and mill construction cost and the drilling discovery rate become as important as the first two parameters. More importantly, by 1995, the market price is projected to be extremely sensitive to the assumed size of the domestic resource base as the price begins to respond to resource depletion effects.

THE CURRENT DOMESTIC OUTLOOK

The events of 1979, to date, have not been particularly supportive of the Nation's nuclear power program. Certainly the accident at TMI will probably have repercussions for some time. In the short term, the accident has apparently brought about a differential consideration, i.e. risk premium, for nuclear versus nonnuclear electric utilities in the eyes of the Nation's financial markets although it is too early to determine if this will have a long-term effect.

While the TMI accident was the most publicized nuclear event of the year, there are also other events outside the context of TMI that mark the year 1979 as a significant one for nuclear power.

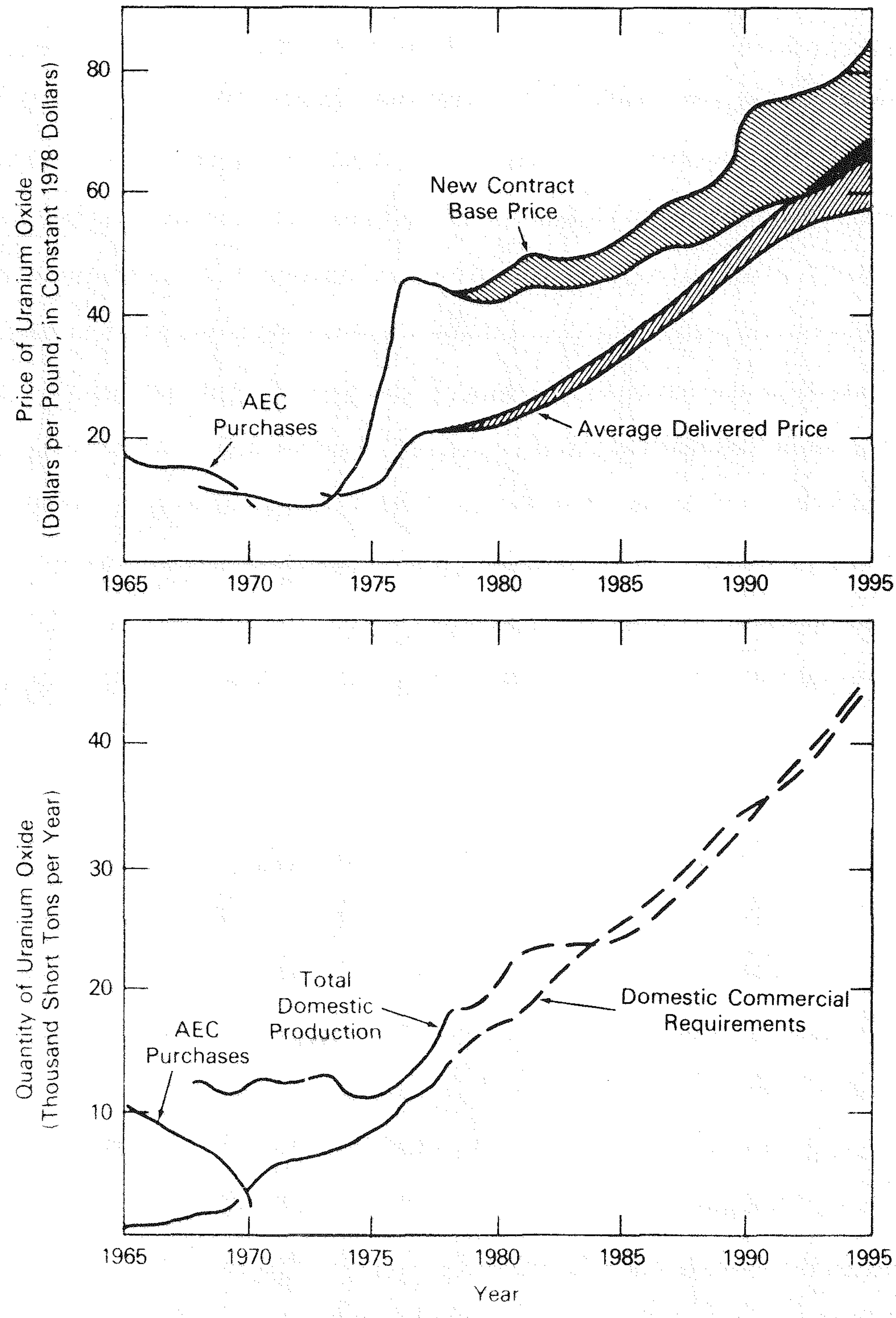

FIGURE 9. *Domestic natural uranium market supply, demand, and price: actual and "Series C," 1965–1995*

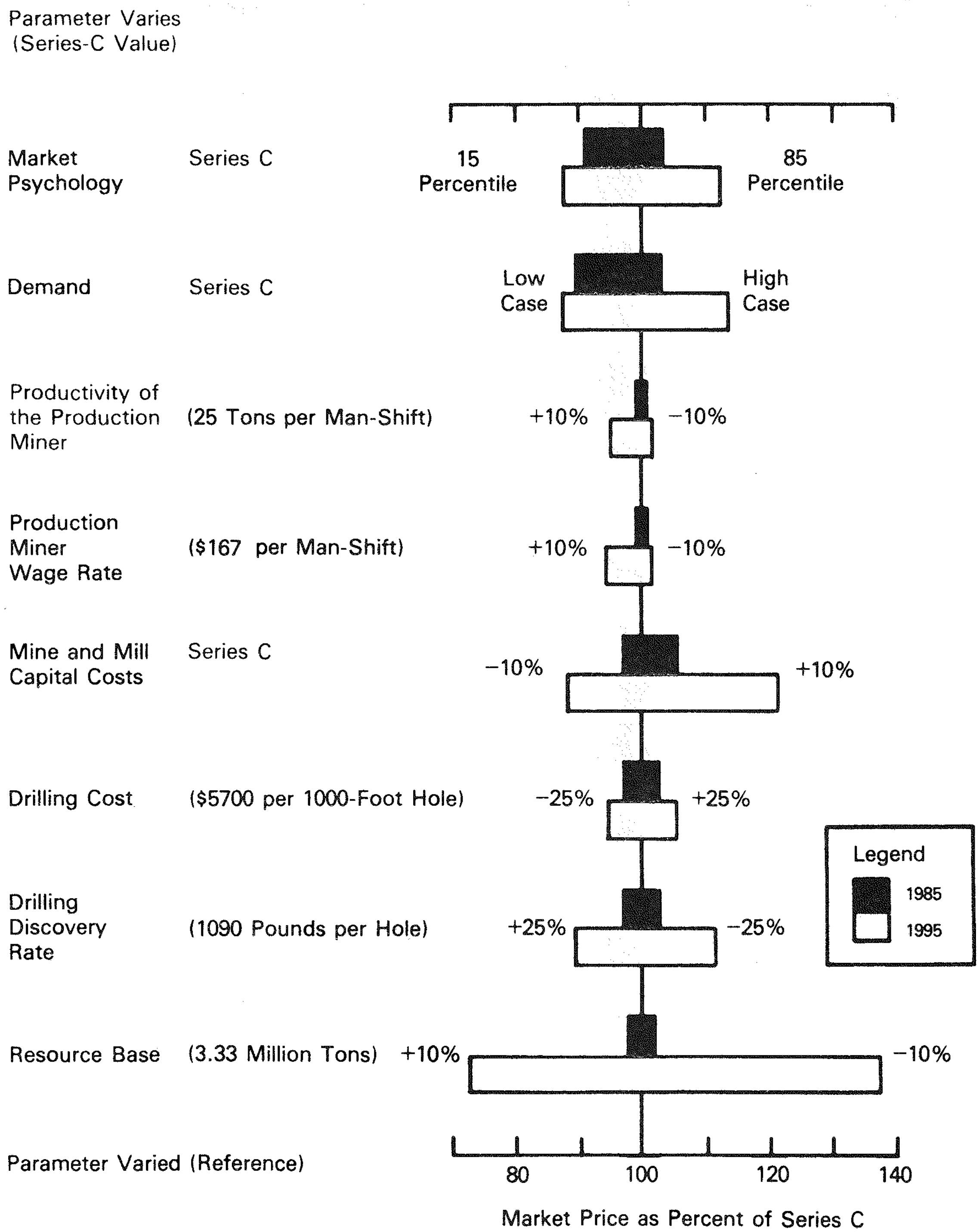

FIGURE 10. *Uranium market price sensitivities: "Series C" reference, 1985–1995*

For example, the Jamesport decision in New York is conclusive evidence that the State's antinuclear position has crystallized. In addition, industry stalwarts, such as TVA, Duke Power Company, and Commonwealth Edison Company have announced major delays in their nuclear construction programs.

These and other events of 1979 have prompted EIA to make a major reevaluation of the nuclear forecasts published in its latest Annual Report. Consideration has been limted to new data introduced in 1979 using essentially the same analytical techniques as before. The effect of new information has been the creation of a "bow wave" of delayed or deferred projects—a "bow wave" that has pushed many trailing projects beyond the midterm period. In addition, the old "Series C" midcase assumes six net new orders over the next 4 years; these orders do not appear likely now.

The results of the reevaluation are shown in table 6 and figure 11. An accurate general conclusion is that the 1995 milestone has been drastically affected with its range being displaced downward by about 30 GWe for 1995. The range for 1990 is about 15 GWe lower while even the 1985 range slipped 5 GWe.

The most recent levels of projected nuclear power are subject to even further erosion as they depend in many cases on the favorable outcome of decisions yet to be made by regulatory agencies and utility management. What portion of the projections can really be considered firm? We have analyzed all domestic nuclear projects in order to assess which are safely beyond the "point of no return", and what, in fact, the "point of no return" really means. At this time last year, a general assumption was that once work had begun on the reactor building foundation, the subject utility company was too deeply committed to turn back since some major components are often being delivered to the site at this state. It now appears that numerous projects, especially successive units at a given site, have had construction activities halted after work on the reactor building foundation has begun and delivery of some major components has taken place.

Under what conditions would the units authorized for construction, but currently stalled, be restarted? Let us first consider those units definitely past the turnback point. Past examples might be Crystal River 3 (Florida Power Corporation) and Cook 2 (American Electric Power), and a good current example is the Braidwood plant (Commonwealth Edison Company). Projects in this category are, or were, stalled only temporarily. There was never any real question about their reactivation because they were halted typically past the 50-percent completion point.

On the other hand, the 19 GWe nuclear generating capacity projects that have been stalled after minor construction activity and the 14 GWe nuclear generating capacity projects that have not yet begun major construction activity, but are authorized to do so, are in a different category. These projects should be very amenable to reactivation and may well be generally awaiting favorable determination of the need for new electric generating capacity as related to perceptions of future load growth, and/or adequate financial strength of the utilities involved. For these projects, the difficulties and uncertainties involved in the licensing process of these projects have been hurdled for the most part. If financing the project were not the overriding concern, then the decision to reactivate the construction program need be made no greater than 8 years prior to the perceived need for new capacity. If the commitment is firm for the addition of new baseload capacity, then there would be no inducement, from an investment standpoint, to

TABLE 6. *Updated domestic nuclear power forecasts (GWe)*

	Annual Report to Congress July 1979			Updated Forecast October 1979		
Year Milestone	Low	Mid	High	Low	Mid	High
1985	102	114	118	95	106	113
1990	142	152	171	129	140	155
1995	186	208	225	156	179	196

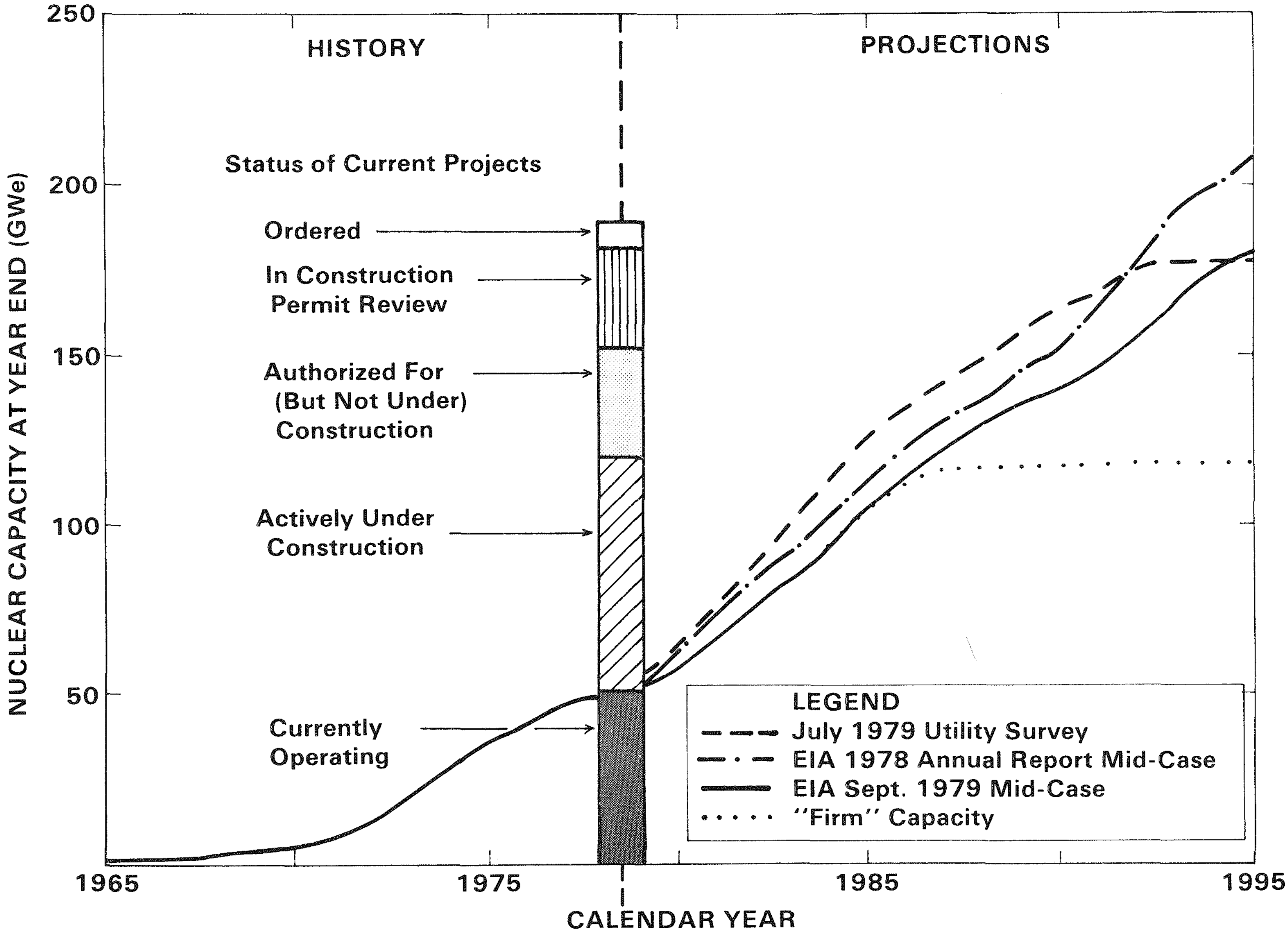

FIGURE 11. *Domestic nuclear power capacity, 1965–1995*

switch to a new comparable sized coal-fired project instead of continuing the stalled nuclear project. Both the construction costs and lead times, from that point forward, would be comparable for the two options. This line of reasoning follows, of course, only if there are no significant impacts on this category of nuclear projects resulting from the Kemeny Commission's deliberations.

The financial-health aspect is related to the structure and behavior of each utility's rate commission and to the financial management capability of the particular utility considered. At one hypothetical extreme, if the rate commission is primarily interested in supporting the addition of generating capacity, its rate decisions, coupled with sound utility financial management, can remove financial health as a constraint for the utility in question. On the other extreme, if the rate commission's only concern is to keep electricity rates from increasing in the short term then its rate decisions, coupled with poor financial management on the part of the utility company, would not support a capacity expansion program. (In the real world, rate commissioners and utility managers wear hats that are shades of gray, rather than pure black or white.) Prior to the 1970s, these two viewpoints were not necessarily in contradiction since the addition of new generating capacity generally resulted in lower electricity rates. In today's world, the cost of producing electricity from new units generally requires higher unit rates except possibly for the replacement of oil-fired baseload capacity with its very high fuel costs.

In summary, about 34 GWe of nuclear generating capacity is "waiting in the wings" for the proper load-growth and/or financial conditions.

What about the 29 GWe of nuclear capacity under construction-permit review? These projects are susceptible to special problems of the licensing process in addition to the load-growth and financial uncertainites of the stalled projects as described above. It is doubtful that any new construction permits will be granted by the NRC before the thorough consideration of any recommendations that may result from the deliberations of the Kemeny Commission. The interactions that have taken place in public between these two bodies indicate the lack of single-mindedness in at least the area of procedural matters. We at EIA have no special insight into the likely outcome of the Kemeny Commission's study, but their report to the President is due at the end of October 1979, so we should all be able to make a judgement soon.

Beyond those nuclear plants already into the licensing process, there are only a few projects that can be identified at this time. The first signal of hope for nuclear power growing beyond the universe of identified projects will be the resumption of new orders for nuclear units. What are the prospects for new orders? It is clear that resolution of the items shown in figure 12 is vital to the long-term prospects of nuclear power. It appears, at the present time, that the first two items are overriding in the eyes of electric utility planners. Without a basic demand for additional electrical capacity and without the financial means to construct that capacity, it matters little whether there is public acceptance of nuclear power or there is the uranium resource base to support a larger nuclear program.

The uranium requirements and uranium market impacts of these updated nuclear power projections are currently being analyzed and will be released as an EIA Analysis Report.

- A substantial increase in central base-load electricity demand is anticipated for post-1990 period.
- A major reassessment is made of utility financial practices and/or rate structures to help relieve debt/equity and cash flow burdens of constructing new generating capacity and, in particular, nuclear baseload capacity.
- The deployment of a nuclear reactor system becomes more predictable and less problematic, and in the minds utility planners, a superior choice over coal systems for both new and replacement base-load service.
- Fuel cycle uncertainties such as long-term uranium availability and waste disposition are effectively addressed and convincingly resolved.
- Environmental and social problems with mining, transporting, and burning of coal become compelling.
- A more diverse and more complete public acceptance of nuclear power is realized.

FIGURE 12. *Factors for an increased nuclear power program*

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OVERVIEW OF NURE PROGRESS FISCAL YEAR 1979

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U. S. Department of Energy

October 1979

INTRODUCTION

The National Uranium Resource Evaluation (NURE) program was initiated by the U.S. Atomic Energy Commission in 1974. The primary reason for creating the NURE program was to provide the U.S. Government with the timely and accurate information, regarding uranium resources of the United States, that is essential for long-range planning decisions for the Federal Nuclear Energy Program activities. Uranium resources are a fundamental part of the Nuclear Fuel Cycle which consists of uranium resources, uranium enrichment, nuclear power plants, and nuclear waste isolation; and timely and accurate information on the Nation's uranium resources and its future availability is essential for making valid, long-range planning decisions on such matters as:

1. What amount and type of uranium enrichment facilities will be needed by the United States in the future?

2. What number and kind of nuclear power plants will be needed in the United States and can be adequately fueled in the future?

3. What types and amounts of nuclear fuel waste will have to be safely isolated on a long-term basis as a result of the U.S. Nuclear Energy Program activities?

A secondary reason for NURE was to provide the U.S. uranium mining industry with NURE-produced information on the Nation's uranium resources, forecasted uranium demand-supply for the United States, and improved uranium exploration and delineation techniques developed by the NURE program.

Since its inception in 1974, NURE has produced two comprehensive progress reports: the Preliminary NURE Report dated June 1976 and the Interim NURE Report dated June 1979. The next comprehensive NURE progress report will be completed in October 1980 and will present the assessment of the Nation's uranium resources based upon all resource data available at that time.

The purpose of this report is to give an overview and summary of the progress of the NURE program since October 1978 when Dr. Donald L. Everhart presented the last annual NURE progress report to the 1978 Uranium Industry Seminar.

MAJOR NURE GOALS AND OBJECTIVES

From the beginning, the long-range goal of NURE has been, and still remains, a reliable assessment of the uranium resources of the continental United States.

However, specific short-range objectives designed as significant milestones toward achieving this long-range goal of NURE have been revised from time to time to satisfy changing needs and priorities for uranium resource assessment information needed for long-range planning of Federal Nuclear Fuel Cycle activities.

In the summer of 1978, the U.S. Department of Energy (DOE) created a NURE Task Force for the purpose to determine how the NURE program could best be restructured to provide earlier resource information for Nuclear Fuel Cycle planning than was then scheduled for the longer range National uranium resource assessment. When the DOE-NURE Task Force was initiated in 1978, the long-range nationwide resource assessment goal of NURE consisted of two principal resource assessment objectives:

1. To assess, by the end of 1983, the uranium resources (reserves and potential resources) of the 272 National Topographic Map Series (NTMS), 1:250,000 scale quadrangles, judged to be most favorable for uranium occurrence; and

2. To assess the uranium resources of the remaining NTMS quadrangles needed to complete the assessment of the uranium resources of the continental United States by the end of 1985.

The NURE Task Force of 1978 resulted in a restructuring of NURE to provide for the addition of the following short-range resource-assessment objectives while maintaining the original 1983 and 1985 long-range resource-assessment goals:

1. To complete by October 1980, a reliable assessment emphasizing the most certain categories of uranium resources (reserves and probable potential resources) in the United States. This objective will result in an assessment of the uranium resources in the 116 "most favorable" NTMS quadrangles.

2. To assess by October 1980, the higher cost (greater than $50 per pound forward cost) uranium resources referred to as Intermediate-Grade Resources (containing between 0.01 and 0.05 percent U_3O_8) at three specified field-test sites. Post-1980 work will extend these resource assessments to cover the geologic environments of the three sites, and additional Intermediate-Grade Resource sites and environments will be studied in future years.

3. To assess by October 1980, the uranium resources of one specified site for the Precambrian quartz-pebble conglomerate type of "world-class"; post-1980 work will extend the "world-class" site assessment studies to the Precambrian quartz-pebble conglomerate geologic environment, and additional types of "world-class" uranium deposits will be studied in future years.

In addition to previously discussed changes in NURE goals, the NURE Task Force directed that an accelerated effort be made to develop improved uranium resource-assessment methodologies, and this directive has been initiated in the restructured program.

Because of several recent cuts in the Fiscal Year 1980 (FY 1980) and FY 1981 NURE budgets, the long-range goal of completing the assessment of the uranium resources in the continental United States has been delayed from the end of 1985 until the end of 1987. All of the short-range NURE resource-assessment objectives discussed above have been retained during the recent budget cuts.

NURE STRATEGY

Resource Assessment

The DOE strategy for achieving the NURE resource-assessment goals and objectives has always been based on the geologic analysis and interpretation of all available geologic and uranium resource data characterized by the distribution and habits of uranium in its natural environment. This strategy has been applied to NURE in two stages:

1. Phase one was to prepare a *preliminary* assessment of uranium resources of the continental United States based on a geologic analysis of all geologic and resource data available to DOE when the NURE program began in 1974. This preliminary assessment has been completed and led to the publication of the Preliminary NURE Report in June 1976.

2. Concurrent with preparation of the Preliminary NURE Report was the initiation of a longer range second phase of NURE which was to acquire those kinds and amounts of additional geologic and uranium resource data to allow a more comprehensive and reliable assessment of the Nation's uranium resources than was possible with phase one of NURE.

The NURE resource-assessment activities are planned and conducted on the basis of the National Topographic Map Series (NTMS), 1:250,000 scale maps. However, actual estimation of uranium resources within the NTMS quadrangles is based on analysis of individual geologic environments. The quadrangles are used as a convenience (regular shapes) for facilitating the planning, scheduling, subcontracting, and measurement of progress toward the nationwide uranium resource assessment.

The general strategy of the present NURE quadrangle resource-assessment activities is based on the following steps:

I. Acquire necessary additional data
   A. Company-confidential Resource Data
   B. Geologic Studies (uranium favorability and deposit modeling)
   C. Aerial Surveys

D. Hydrogeochemical Surveys
E. Subsurface Investigations
F. Geophysical Surveys

II. Geologic integration and analysis of all data

III. Resource estimation.

DOE applies this quadrangle resource assessment strategy in two discreet phases to protect the confidentiality of the large amount of company-confidential resource data used to make the assessments: the quadrangle evaluation phase, and the quadrangle assessment phase.

The quadrangle evaluation activities are conducted to identify areas within quadrangles most geologically favorable for the occurrence of uranium deposits or districts, and this information is fundamental to the assessment process. The results of the quadrangle evaluations will be published as Quadrangle Folios that delineate and discuss the favorable areas determined during the investigations.

The quadrangle resource assessments are *not* individually published so as to protect the confidentiality of individual sets of company-confidential data that led to the quadrangle resource assessments. However, cumulative or aggregated resource assessments that do not reveal individual sets of company-confidential data are published by DOE as annual updates, and occasionally as special resource-assessment reports such as: the Preliminary NURE and Interim NURE Reports discussed previously.

The foregoing resource-assessment strategy for the NURE quadrangle resource assessment on a nationwide basis is also being used for the Intermediate-Grade and World-Class Resource investigations initiated at the beginning of FY 1979. However, these two new NURE resource-assessment projects are not being planned or conducted on the NTMS quadrangle basis, but they are conducted as topical resource studies at "sites" which contain a few square miles, and which are specifically selected from the geologic environment or areas containing the specific type of uranium deposit.

If the October 1980 resource assessments of the Intermediate-Grade and World-Class sites being studied in FY 1979 and FY 1980 are encouraging, the resource-assessment studies will be continued beyond FY 1980 to cover the geologic environments containing the specific field sites.

Technology Applications

A NURE Technology Applications activity is being conducted that has the following major goals:

1. To develop needed new and improved concepts, techniques, and instrumentation for uranium resource assessment, exploration, and production;

2. To provide field calibration facilities and quality control for instrumentation and techniques used by DOE, contractors, and industry for resource assessment, reserve estimation, exploration, and production; and

3. To evaluate, demonstrate, and transfer improved technology for exploration, evaluation, and exploitation by industry.

The strategy used to maximize the NURE Technology Applications goals is to: (1) identify those technology areas that would most sensitively impact on the NURE program goals and objectives, (2) plan, program, and budget for those subcontracted and inhouse activities designed to best achieve the technology needs, (3) implement, monitor, and control the identified technology activities, and (4) facilitate the transfer of the needed technology to the uranium industry, and to NURE when appropriate.

An example of the use of the above NURE Technology Applications strategy was the early recognition by DOE that the gross gamma logging methodology that had served the domestic uranium exploration industry so well for several decades would not continue to be as effective or reliable, as industry moves in the future to explore for ores that are not in equilibrium, or for lower grade uranium deposits. Therefore, DOE determined that the full and efficient achievement of future NURE resource-assessment goals would require the development and commercialization of a fission neutron logging probe that would provide for direct detection of the presence of uranium in boreholes (direct uranium logging) to alleviate the inherent inaccuracies of estimating uranium concentrations in ores with disequilibrium or for low-grade uranium deposits. Delayed fission (DFN) and prompt fission neutron (PFN) logging technologies, maximized for uranium exploration, have now been developed by NURE and will soon be commercialized by the domestic uranium logging industry.

NURE PROGRESS—FY 1979

Only a brief overview statement will be given on the progress made during FY 1979 for each of the major NURE program activities (see figure 1). Several papers to be presented at this Seminar will discuss more completely the progress made during FY 1979 on: U.S. Geological Survey NURE activities, quadrangle evaluation and assessment, uranium reserves and potential resource activities, industry uranium exploration activities, low-grade uranium studies, uranium production, and production capability.

Geologic and Related Investigations
- Aerial Surveys
- Hydrogeochemical Surveys
- Subsurface Investigations
  - Quadrangle assessment drilling
  - World-Class resource drilling
  - Intermeditate-Grade resource drilling
  - R & D support drilling
  - National logging activity
- Quadrangle Evaluation and Assessment
- Intermediate-Grade Resource Studies
- World-Class Resource Studies

Technology Applications

FIGURE 1. *Main NURE program activities FY 1979*

Aerial Surveys

National Aerial Reconnaissance Survey—The National Aerial Radiometric and Magnetic Reconnaissance Survey provides high sensitivity aerial radiometric and magnetic data being used for the Quadrangle Assessment, Intermediate-Grade Resource, and World-Class Resource studies of NURE. These reconnaissance surveys are flown with a low-density, flight-line spacing to identify the near surface regional distribution and concentration characteristics of potassium, uranium, and thorium, which are interpreted to identify broad regions considered favorable for the occurrence of large uranium deposits or districts. This National Aerial Reconnaissance Survey will lead ultimately to the preparation of a National Radioelement Distribution Map which should be beneficial in many ways in the future to the earth science communities of the United States.

During FY 1979, 189,242 flight-line miles of reconnaissance surveying were completed. During the year, 127 aerial reconnaissance survey reports were published as DOE open-file reports, and 113 aerial reconnaissance quadrangle surveys were in progress (see figures 2 and 3).

Geologic interpretation of previously completed aerial reconnaissance surveys contributed to the FY 1979 quadrangle assessment activities and identified several small areas which deserved detailed aerial radiometric or other type of follow up studies.

The National Aerial Reconnaissance Survey will continue in FY 1980 to support NURE resource assessment goals.

Detailed Aerial Surveys—Beginning in FY 1979, detailed aerial surveys consisting of high-density flight-line spacings (usually one mile or less) were flown over some selected small areas interpreted as especially favorable for occurrence of uranium from the analysis of the National Reconnaissance Surveys. About 48,000 flight-line miles were flown on 17 detailed aerial surveys in progress during the year (see figures 4 and 5).

Detailed aerial surveys will be continued to provide timely information needed to support the FY 1980 NURE resource-assessment goals.

Hydrogeochemical Surveys

HSSR Survey—The National Hydrogeochemical Stream-Sediment Reconnaissance Survey (HSSR) provides geochemical data from the Nation's surface waters, stream sediments, and ground waters to be used for the Quadrangle Assessment, Intermediate-Grade Resource, and World-Class Resource studies of NURE. These surveys include low-density reconnaissance sampling by quadrangle to identify broad geochemical trends that can be used to identify areas favorable for occurrence of uranium deposits.

During FY 1979, 58 HSSR Survey reports were completed and published as DOE open-file reports, and hydrogeochemical investigations were in progress for 292 HSSR quadrangle surveys (see figures 6 and 7).

These HSSR surveys will continue in FY 1980 to support all NURE resource-assessment goals.

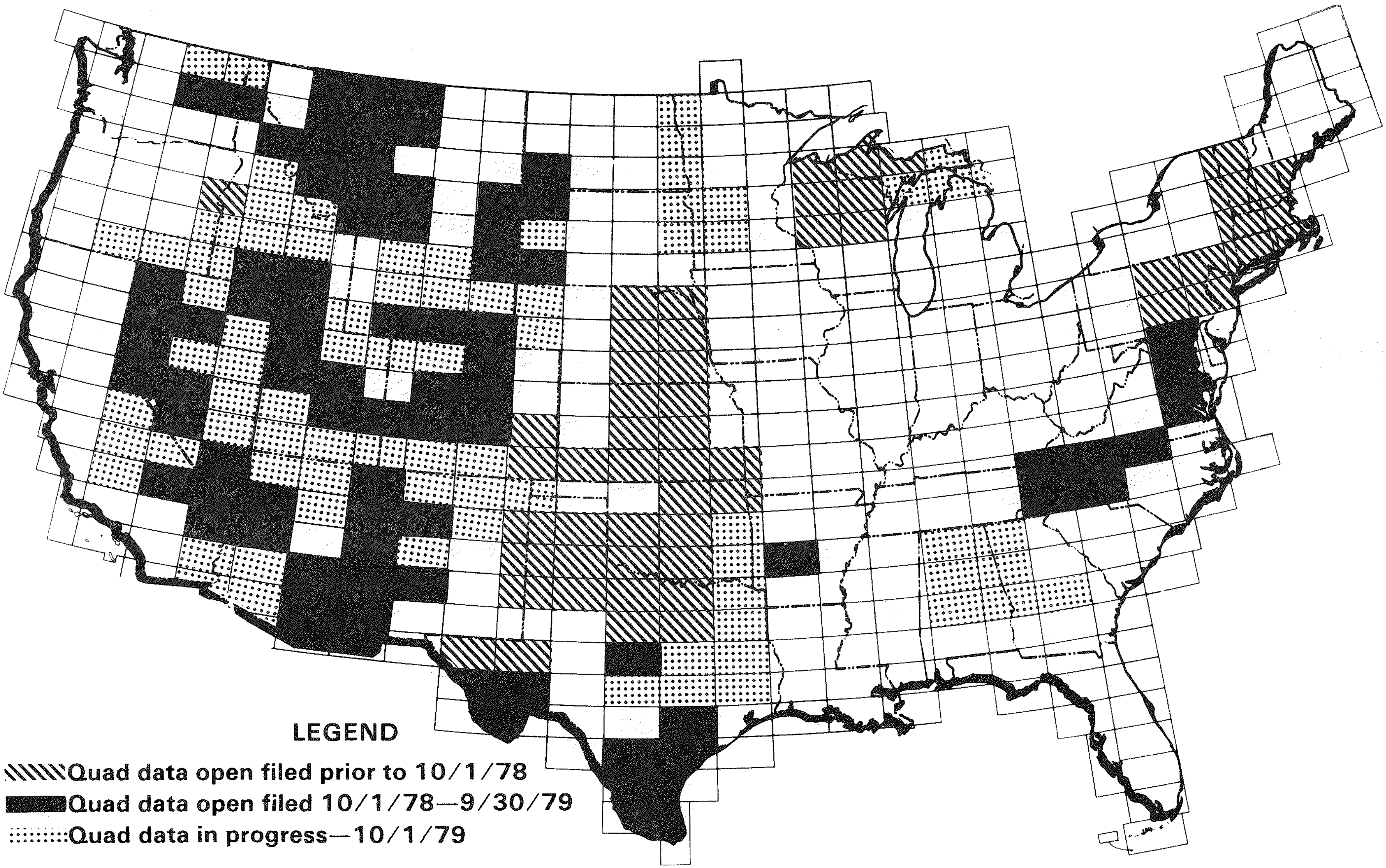


FIGURE 2. *Status of aerial radiometric reconnaissance survey—FY 1979*

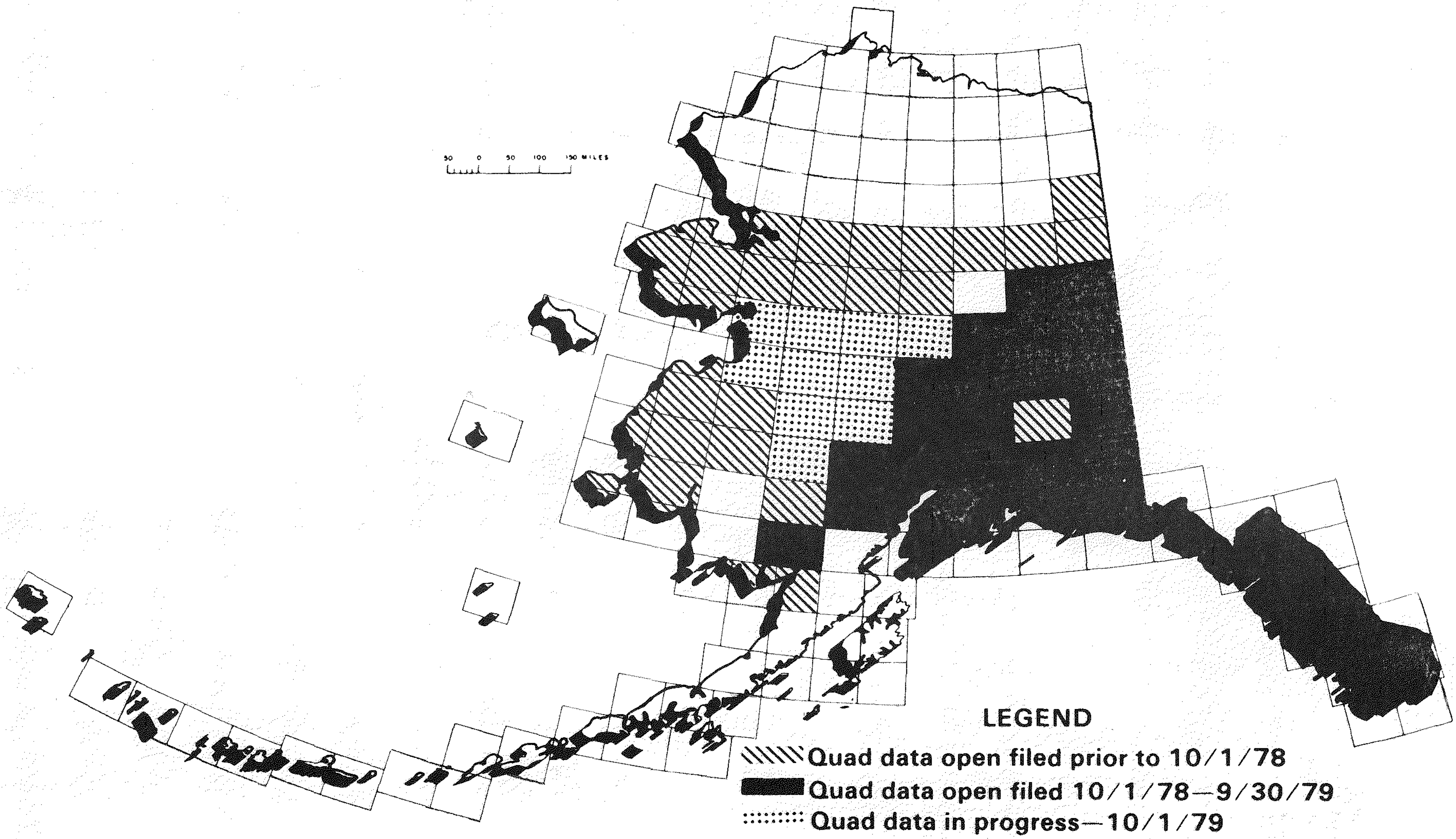


FIGURE 3. *Status of aerial radiomentric reconnaissance survey—FY 1979*

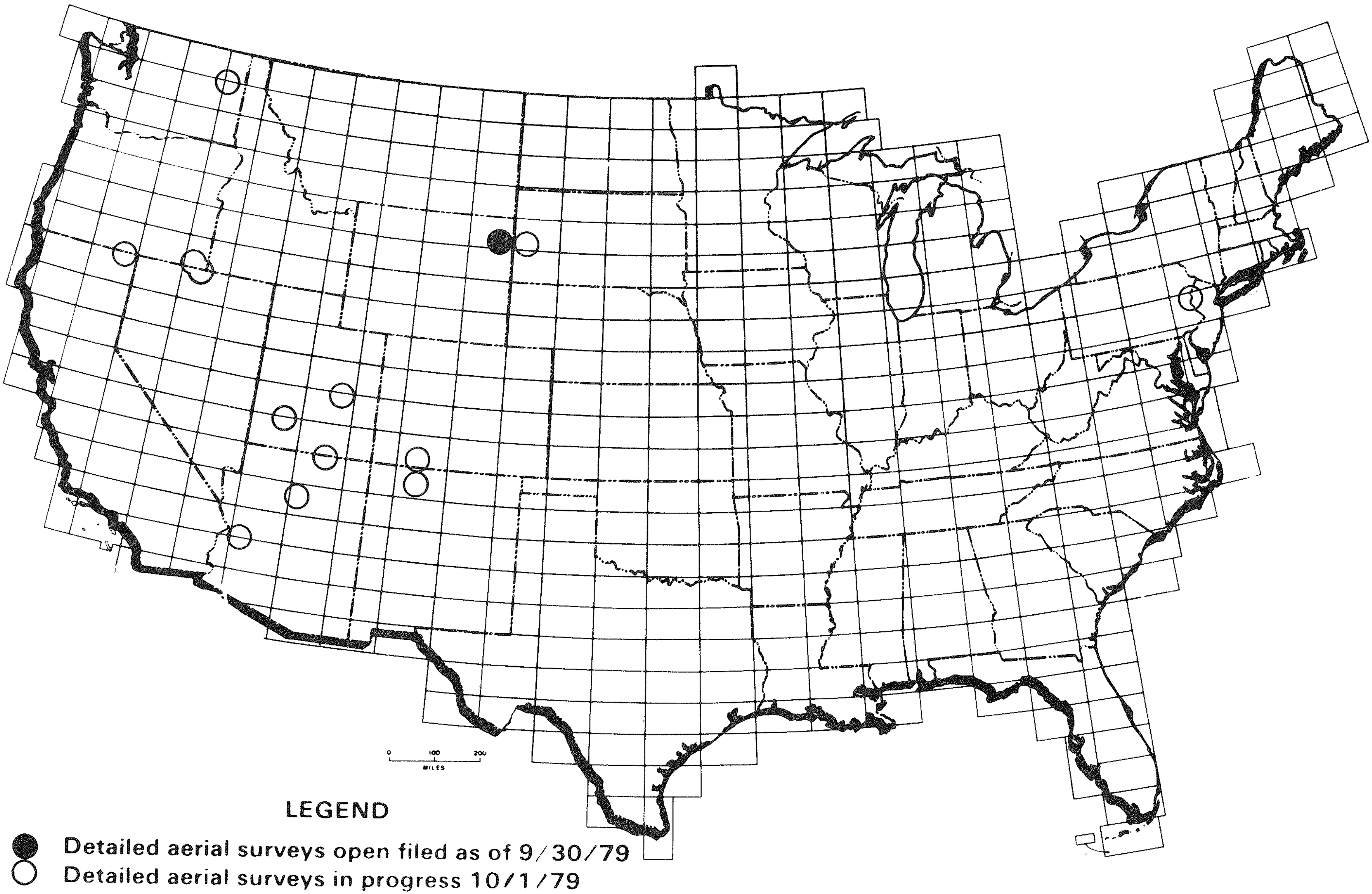


FIGURE 4. *Status of detailed aerial surveys—FY 1979*

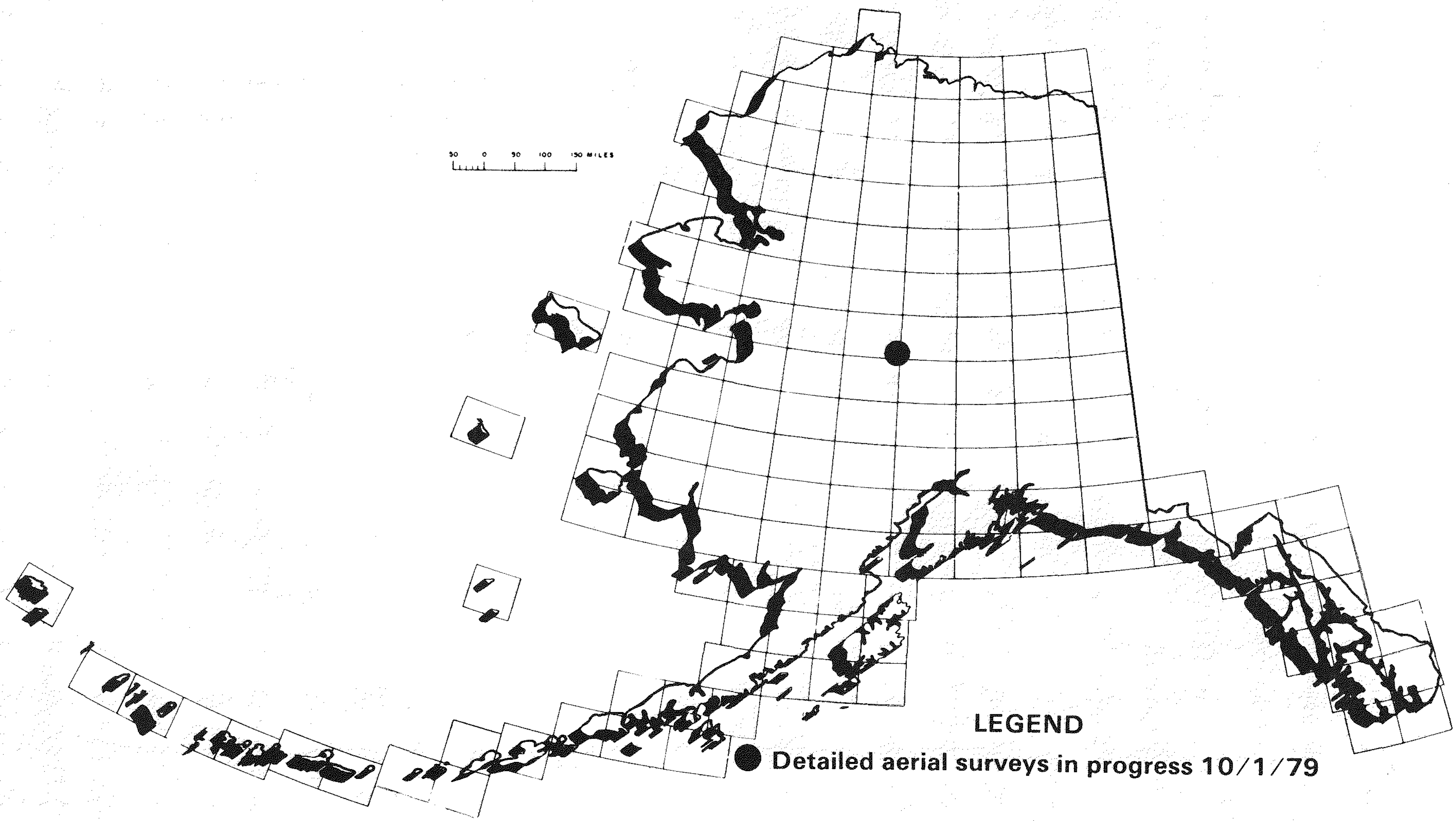


FIGURE 5. *Status of detailed aerial surveys—FY 1979*

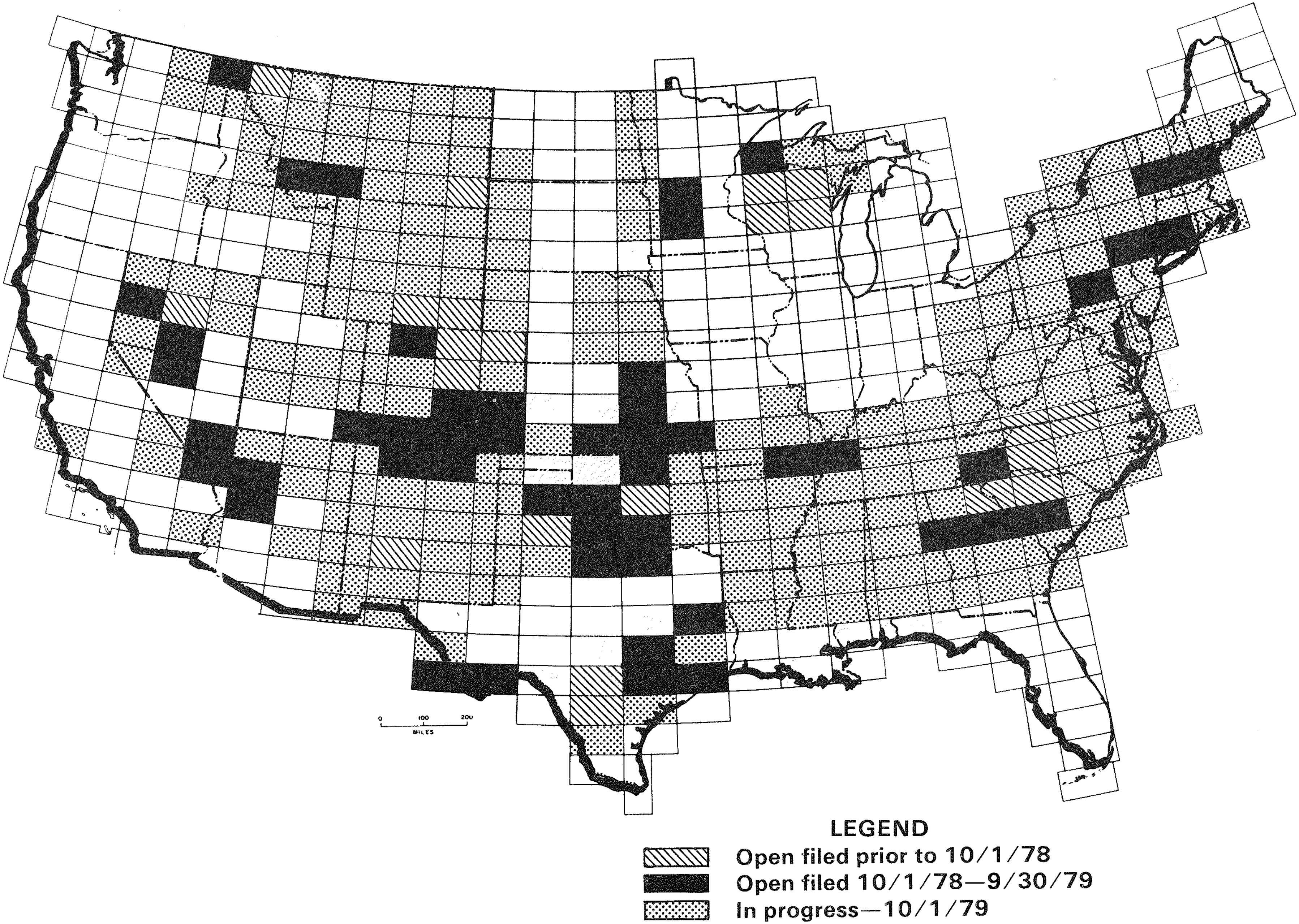


FIGURE 6. *Status of HSSR survey—FY 1979*

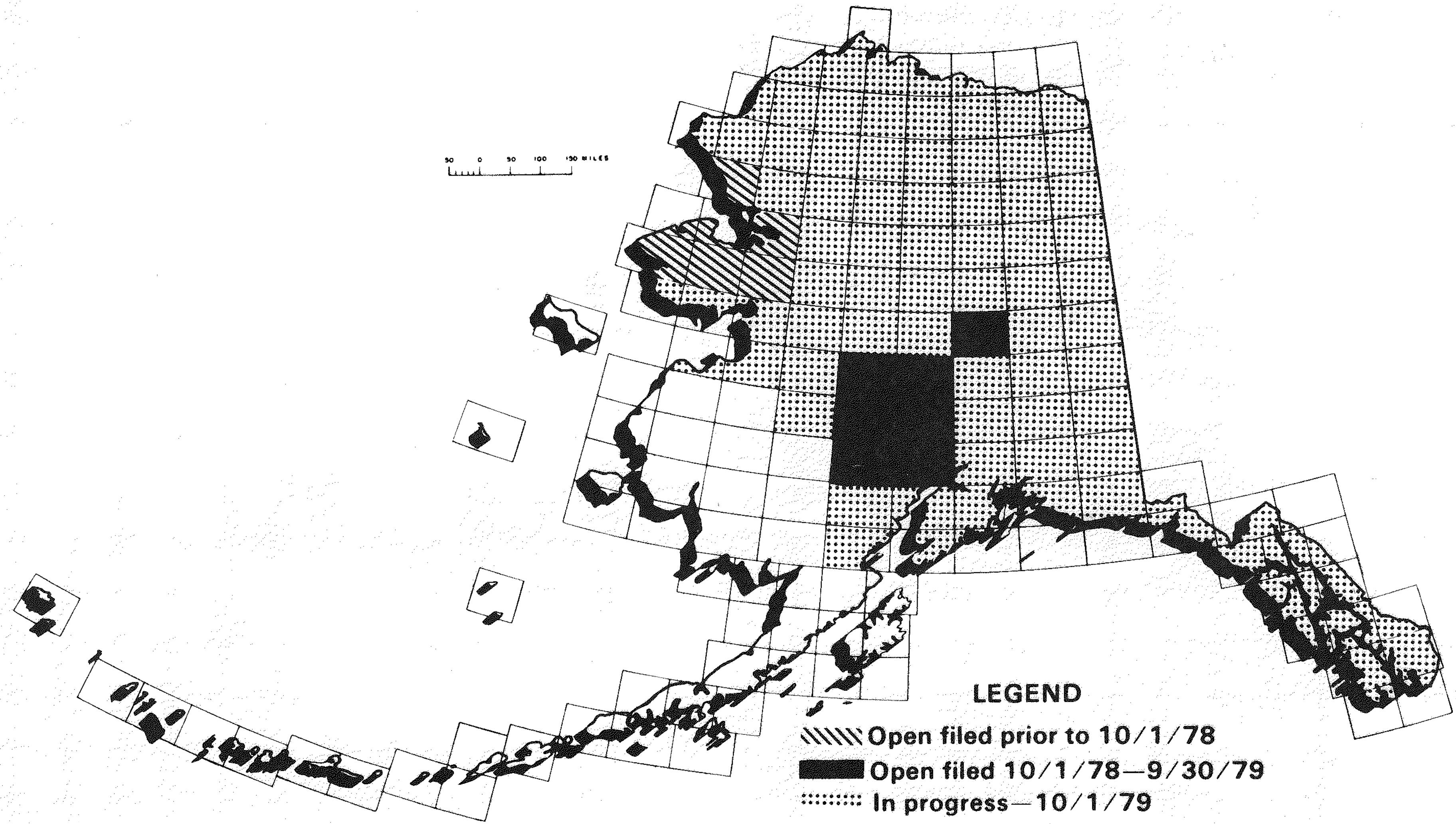


FIGURE 7. *Status of HSSR survey—FY 1979*

Detailed Hydrogeochemical Surveys—Detailed hydrogeochemical surveys consisting of high-density sampling of local areas near inferred deposits or in areas of particularly favorable geology were started in FY 1979. During the past year, one detailed geochemical survey was completed and published, and 26 additional detailed surveys (covering 28 separate areas) were in various stages of progress (see figure 8).

These detailed geochemical surveys will be continued during FY 1980 to support the Quadrangle Assessment, Intermediate-Grade Resource, and World-Class Resource studies.

Subsurface Investigations

Quadrangle Assessment Drilling—Quadrangle assessment drilling provides additional subsurface information necessary to make more reliable quadrangle resource assessments. During FY 1979, nine quadrangle assessment drilling projects were in progress; these totaled about 142,000 feet of drilling by September 30, 1979 (see figure 9).

The quadrangle assessment drilling conducted in FY 1979 has already proved to be helpful in modifying the potential resource estimates previously made in the Preliminary NURE Report for some potential resource areas. For example, assessment drilling has resulted in the previous resource estimates for the East Chaco Canyon area, New Mexico, being revised significantly upward; whereas, the previous estimates for the Spor Mountain area, Utah, were revised downward.

Quadrangle assessment drilling will continue to support the FY 1980 116 Quadrangle Resource Assessment goal.

To date, 2,374 feet of assessment drilling has been conducted to support the USGS studies of thorium resources at Lemhi Pass, Idaho.

World-Class Resource Drilling—During the summer of 1979, drilling was initiated at two sites to study possible uranium resources of the Precambrian quartz-pebble conglomerate type of World-Class Uranium Deposits that might exist in southeast Wyoming and western South Dakota (see figure 9). By September 30, 1979, about 11,000 feet had been drilled at both of these sites, and preliminary results of the drilling in southeast Wyoming appeared encouraging. Drilling at these two sites will continue in FY 1980 to further evaluate the potential.

Intermediate-Grade Resource Drilling—Drilling in support of the newly initiated Intermediate-Grade Resource Assessment Project was started in FY 1979. About 6,900 feet were drilled to test the potential for occurrence of intermediate-grade uranium deposits in the Brushy Basin Shale Member of the Jurassic Morrison Formation, in a specific area of the San Rafael Swell area, Utah (see figure 9). This reconnaissance-type project has been completed, in as much as the planned drilling did not produce encouraging results.

During FY 1979, about 4,700 feet were drilled to test for existence of intermediate-grade uranium deposits in the Great Divide Basin (Red Desert), Wyoming area.

Drilling in FY 1980 is expected to concentrate on the Copper Mountain, Wyoming, and Great Divide Basin (Red Desert), Wyoming, Intermediate-Grade Resource Sites selected late in FY 1979. A modest amount of drilling may be done in late FY 1980 at the Sand Wash Basin, Colorado, site that was also selected in late FY 1979 for detailed resource studies.

Research and Development Drilling—Drilling designed to obtain cores and subsurface information at specific subsurface locations, in support of R and D projects designed to detect physical or chemical "halos" around orebodies of three types, was conducted at three sites during FY 1979 (see figure 9). About 45,000 feet were drilled to support these three R and D projects in FY 1979, and some drilling will continue on these sites in FY 1980.

National Logging Activity—A NURE National logging program activity was initiated in FY 1979 to obtain subsurface uranium resource information from holes drilled by industry for purposes other than uranium exploration: for example, petroleum, natural gas, or ground water drill holes. This activity does provide resource information critical to the long-range nationwide resource assessment goal of NURE, at a fraction of the cost that would be necessary if the NURE program had to finance drilling of the holes to get the needed subsurface information.

During FY 1979, three contracts to obtain geophysical logging information from drill holes in six

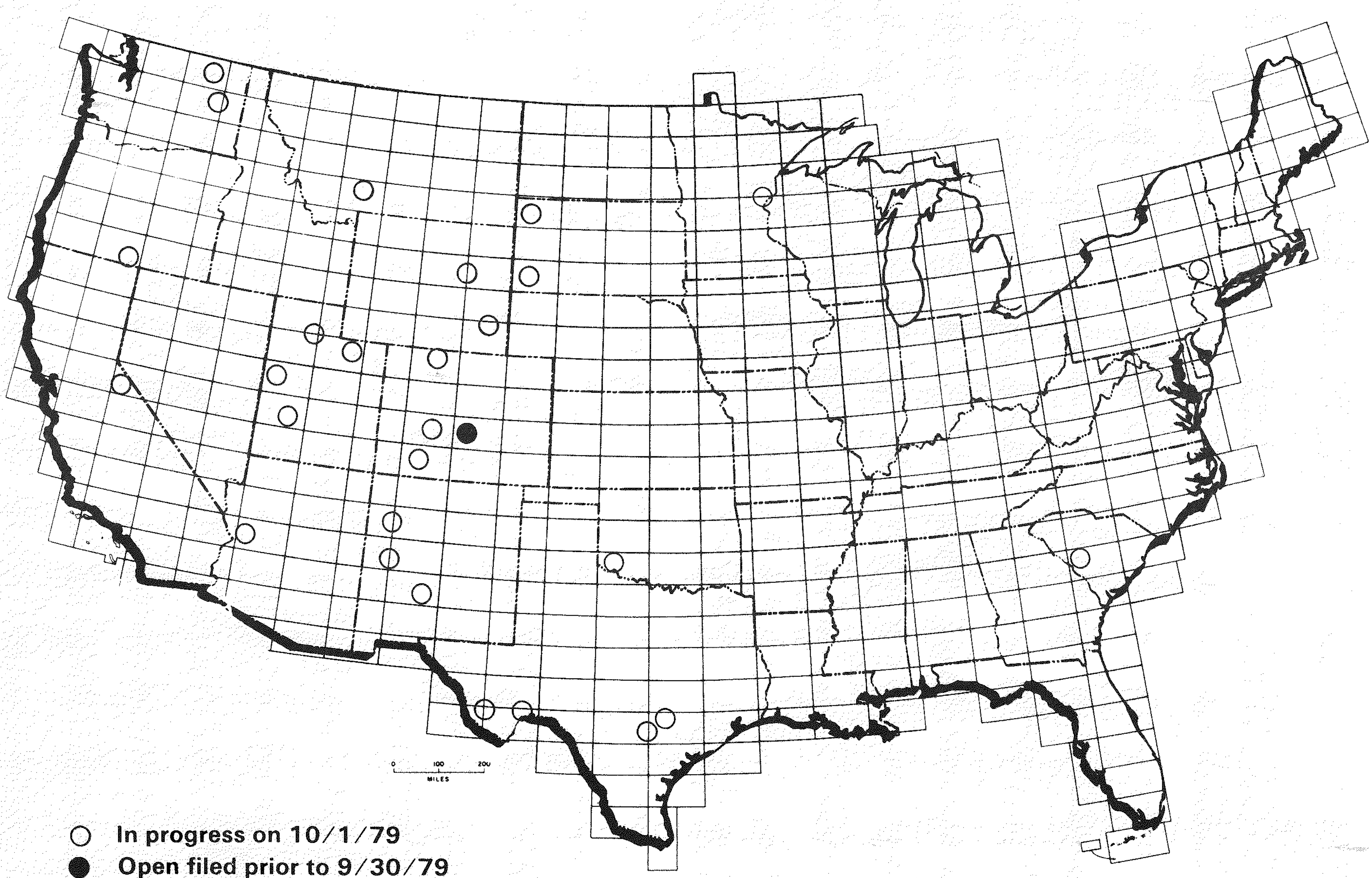


FIGURE 8. *Status of detailed hydrogeochemical surveys—FY 1979*

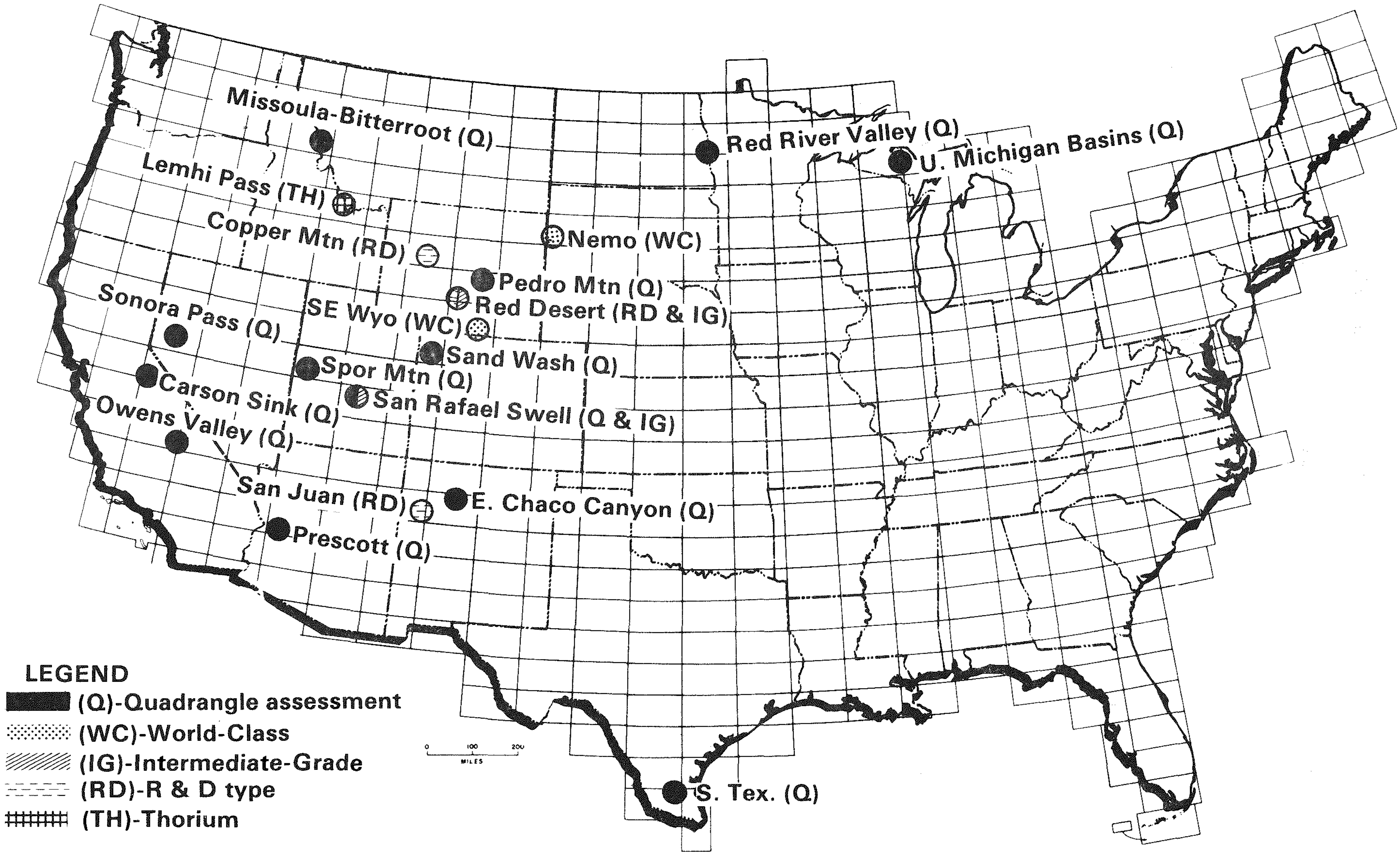


FIGURE 9. *Subsurface geologic investigations projects in progress—FY 1979*

areas of the United States were initiated (see figure 10).

The national logging contractors are to identify drill holes that will satisfy NURE geophysical logging needs, to make arrangements for environmental permits and company permission to log the holes, and to obtain the geophysical logs that will satisfy DOE geophysical logging specifications.

In cased holes, gross gamma-ray and neutron logs will be obtained. For uncased holes, the following logs will usually be obtained: gross gamma-ray, neutron, self-potential, resistivity, temperature, gamma-gamma density, and caliper. Some spectral gamma logs (KUT) will be obtained in the future when these logs are available on a commercial basis from industry.

At the end of FY 1979, 137 holes had been logged with a total cumulative logging footage of about 305,000 feet. The National logging activity is already beginning to provide subsurface radiometric information in a few specific areas that are expected to influence future resource-assessment activities for those areas.

The National logging activity is to continue in FY 1980 at a higher level than for FY 1979.

Quadrangle Evaluation and Assessment

The NURE goal of assessing the uranium resources of the 116 "most favorable" NTMS quadrangles by the end of FY 1980 is on schedule. By September 30, 1979, quadrangle evaluations and assessments had been completed for 18 quadrangles, as was scheduled when the NURE program was restructured at the beginning of FY 1979 (see figures 11, 12, and 13). Although this leaves 98 of the 116 quadrangle evaluations and assessments to be completed during FY 1980, the supporting activities (such as aerial and hydrogeochemical surveys, and quadrangle assessment drilling) have been scheduled to meet the FY 1980 quadrangle evaluation and assessment milestones. Barring unforeseen difficulties, the FY 1980 quadrangle resource-assessment goal will be achieved.

Plainview	Scranton	Sandpoint
Athens	Spartanburg	Mt McKinley
Crystal City	Kingman	Talkeetna
La Junta	Prescott	Lime Hills
Lamar	Williams	Tyonek
Seguin	Spokane	Greensboro

FIGURE 11. *Status of 116 quadrangle evaluation and assessment activity quadrangle completions—FY 1979*

During FY 1979, the following standard procedures for conducting NURE quadrangle evaluation and assessment activities were established: (1) classification of uranium deposits—(published), (2) geologic characteristics of environments favorable for uranium deposits—(published), (3) recognition criteria for uranium deposits—(published), (4) comparative models for resource assessment (under continuing development), and (5) manual for resource assessment—(in preparation).

More detailed discussions of the NURE quadrangle evaluation and assessment activities conducted during FY 1979 will be presented in other papers to be given at this Seminar, and these subjects will, therefore, not be further discussed.

Intermediate-Grade Resource Studies

A new NURE activity to emphasize the assessment of intermediate-grade uranium resources (containing between 0.01 and 0.05 percent U_3O_8) was initiated in FY 1979 as a result of the NURE Task Force recommendations related to the need to expand the Nation's high cost (greater than $50 per pound forward cost) uranium resource base.

Initial work on the new Intermediate-Grade Resource study was directed at reviewing all company-confidential resource data and any NURE-produced data to identify those areas that appeared promising with regard to the possible occurrence of large tonnages of intermediate-grade uranium. From this preliminary analysis of available data, a list of about 60 "candidate" areas was compiled in early FY 1979.

The next phase of the project consisted of discussing the intermediate-grade resource potential with some of the property owners and conducting preliminary field investigations of the more promising candidate sites. This phase of study resulted in a reduction in number of candidate sites to 11 by late spring of 1979. Further discussions with company personnel and more extensive field investigations resulted in the final selection of three sites that appeared to have sufficient promise to justify a detailed study to reliably assess the intermediate-grade uranium resources that exist at the three

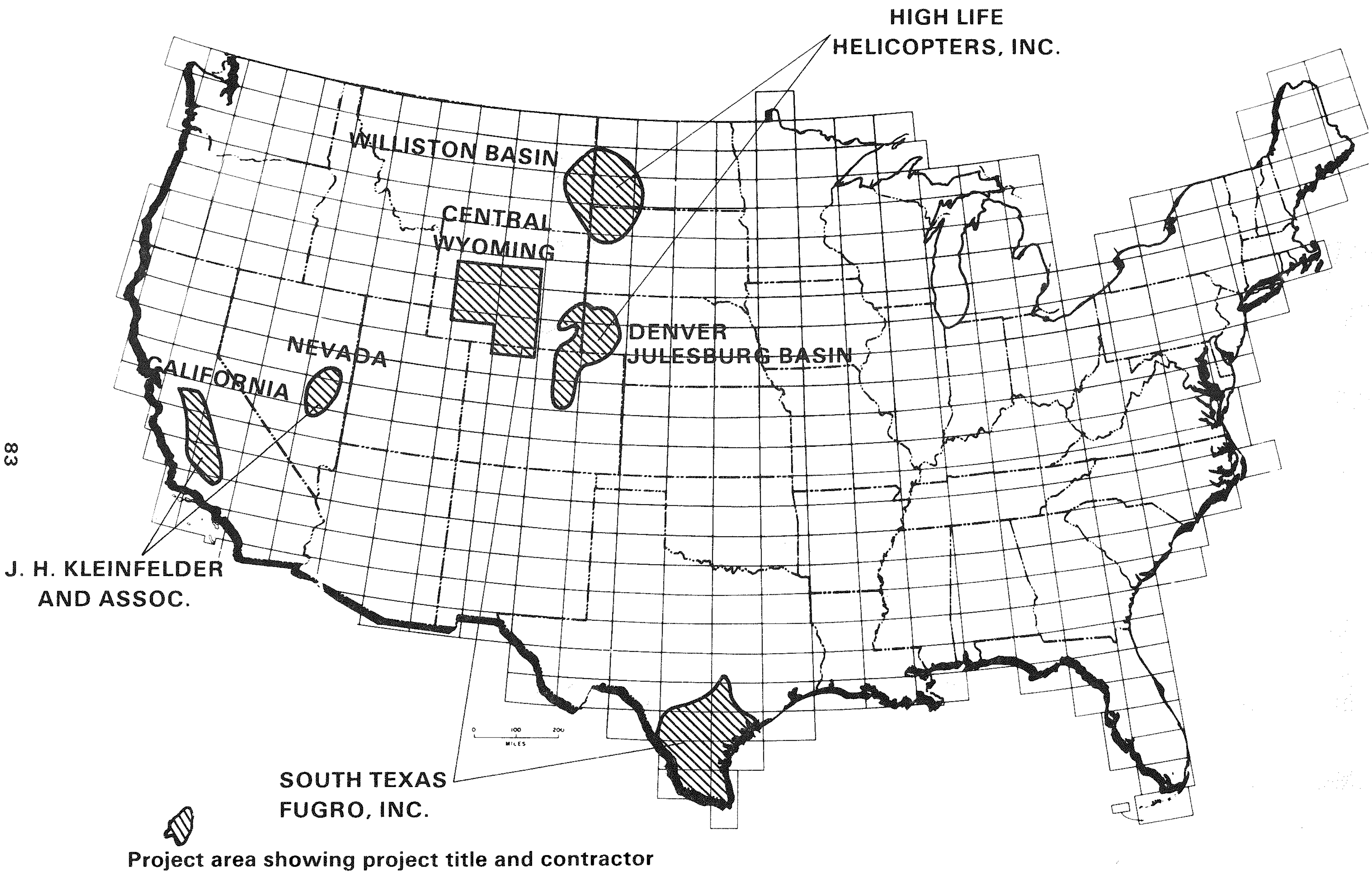


FIGURE 10. *National logging activities—FY 1979*

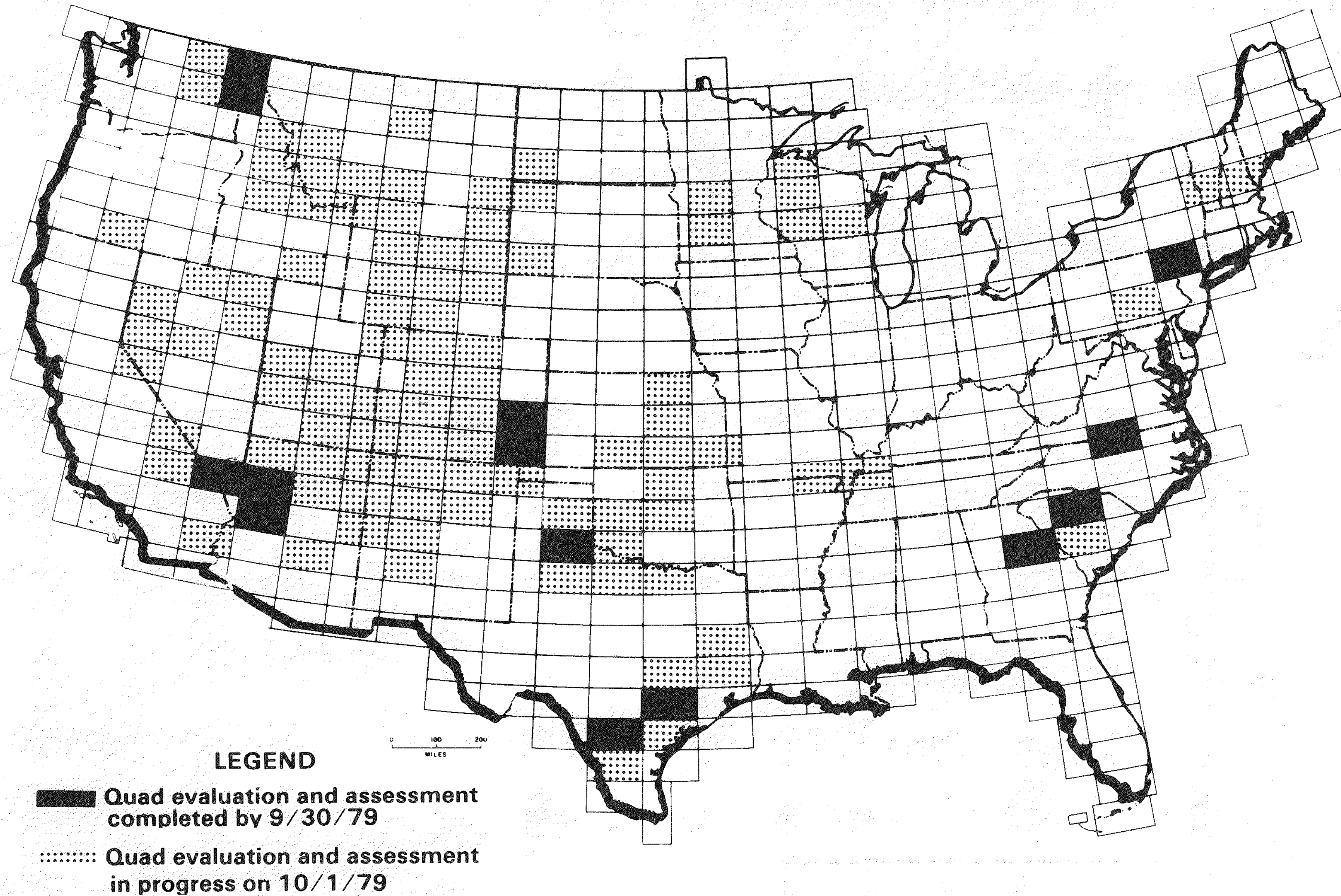


FIGURE 12. *Status of 116 quadrangle evaluation and assessment activity—FY 1979*

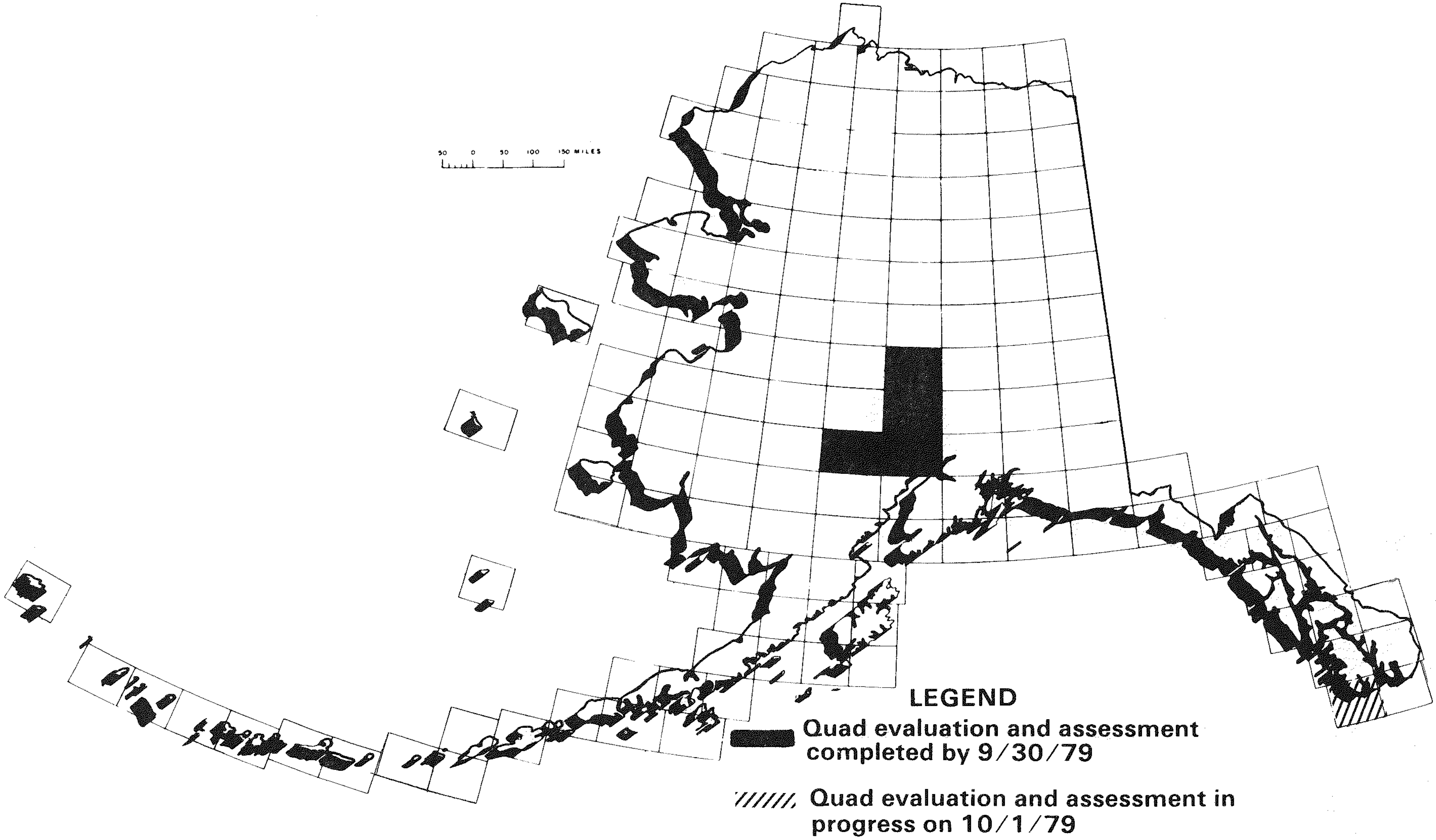


FIGURE 13. *Status of 116 quadrangle evaluation and assessment activity—FY 1979*

selected sites by the end of FY 1980. The three field sites selected will each consist of a few square miles in area and will be located in the following uranium-bearing areas: (1) Copper Mountain, Wyoming, (2) Great Divide Basin, Wyoming, and (3) Sand Wash Basin, Colorado (see figure 14).

Each of the intermediate-grade site studies will be cooperative DOE-Company investigations, and cooperative agreements have either been completed or are in progress with the appropriate companies for each selected field location. Arrangements have been made (or are in progress) to acquire company data from the three sites for resource analysis which will be done in early FY 1980. The geologic objectives and general work plan for FY 1980 activities at the three sites are shown on figures 15, 16, and 17.

World-Class Resource Studies

The World-Class Resource Studies project was initiated at the beginning of FY 1979 to determine whether or not some types of uranium deposits being developed in other countries, but as yet unknown in the United States, might actually be present in this country. The basic approach is to analyze, or model, the geologic environments of the world-important (World-Class) uranium deposits, and to use these World-Class models as a guide for the geologic evaluation of analogous geologic environments in the United States.

Great Divide Basin, Wyoming

- Geologic Target
  Uranium in fluvial and lake sediments of Eocene Battle Spring Formation
- Type of Study
  Utilization of industry geologic, geophysical, and drilling data, augumented with similar NURE data
- FY 1980 Plan
  Analyze company data
  KUT logging of company drill holes
  Limited DOE drilling
  Geologic, geochemical, and geophysical studies
  Data integration, evaluation and reporting
  Site assessment—October 1980
- Possible Results
  100,000 tons U_3O_8 by October 1980

FIGURE 16. *Uranium resource assessment—intermediate-grade resources*

A preliminary study of the geologic characteristics of the better-known World-Class deposits led to the selection of the Precambrian quartz-pebble conglomerate type of deposits to be emphasized on this project in FY 1979 and FY 1980. After a reconnaissance type study was made of the areas in the U.S. considered favorable for occurrence of uranium in conglomerate, field sites associated with

Copper Mountain, Wyoming

- Geologic Targets
  Primary—shear zones in Precambrian granite of thrust plate
  Secondary—sandstone of Eocene Tepee Trail Formation
- Type of Study
  Utilization of industry geologic, geophysical, and drilling data, augumented with similar NURE data
- FY 1980 Plan
  Analyze company data
  KUT logging company drill holes
  Limited DOE drilling
  Geologic, geochemical, and geophysical studies
  Data integration, evaluation and reporting
  Site assessment—October 1980
- Possible Results
  50,000 tons U_3O_8 by October 1980

FIGURE 15. *Uranium resource assessment—intermediate-grade resources*

FIGURE 14. *NURE sites selected for intermediate-grade resources-assessment studies*

Sand Wash Basin, Colorado

- Geologic Target
  Primary—sandstone of Miocene Browns Park Formation
  Secondary—sandstones of Eocene Wasatch and
  Fort Union Formations
- Type of Study
  Utilization of industry geologic, geophysical, and drilling data, augumented with similar NURE data,
- FY 1980 Plan
  Analyze company data
  KUT logging of company drill holes
  Limited DOE drilling
  Geologic, geochemical, and geophysical studies
  Data integration, evaluation and reporting
  Site assessment—October 1980
- Possible Results
  50,000 tons U_3O_8 by October 1980

FIGURE 17. *Uranium resource assessment—intermediate-grade resources*

known uranium occurrences in the Black Hills, South Dakota, and in the Sierra Madre-Medicine Bow Mountains area, southeastern Wyoming, were selected for further work, including drilling (see figures 18 and 19).

A total of 25 drill holes was planned to evaluate the southeast Wyoming site (see figure 20), and five holes were planned to evaluate the Black Hills site (see figure 21). Drilling was started on both of these sites during this last summer, and by September 1979, about 9,000 feet had been completed. Results of this drilling has led to the selection of the southeastern Wyoming site as the one area that will be intensely studied during FY 1980. The potential uranium resources of this site will be assessed in a special World-Class uranium resource-assessment report to be prepared as part of the October 1980 NURE Report.

Preliminary geologic studies will continue in FY 1980 at seven other potential conglomerate locations within the favorable belt of Proterozoic rocks being evaluated (see figure 19).

Technology Applications

Major Objectives for FY 1979-80—When NURE was initiated, DOE personnel determined that the effective achievement of the long-range goals of NURE would be most sensitive to the improvements in three areas of uranium exploration technology: (1) borehole logging, (2) aerial surveying, and (3) development of integrated exploration systems for identifying "halos" around uranium deposits (see figure 22). Successful development of these identified technologies should greatly reduce the cost of industry's uranium exploration activities as well as make the NURE program more cost effective. For these reasons, the objectives for improvements in exploration technology were adopted several years ago and represented the major NURE technology applications activities during FY 1979 and FY 1980. A brief discussion of FY 1979 progress in each of these technology areas follows.

Borehole Logging—Significant progress in developing improved borehole logging technology was achieved in FY 1979. Progress on the following borehole logging technology activities is noteworthy.

1. Direct Uranium Logging
   - The prompt fission neutron (PFN) probe has been successfully tested and evaluated. The improved tube (Zetatron) is expected to be commercialized by December 1980.
   - The delayed fission neutron (DFN) probe has been successfully tested and evaluated. This technology is to be transferred in December 1979.

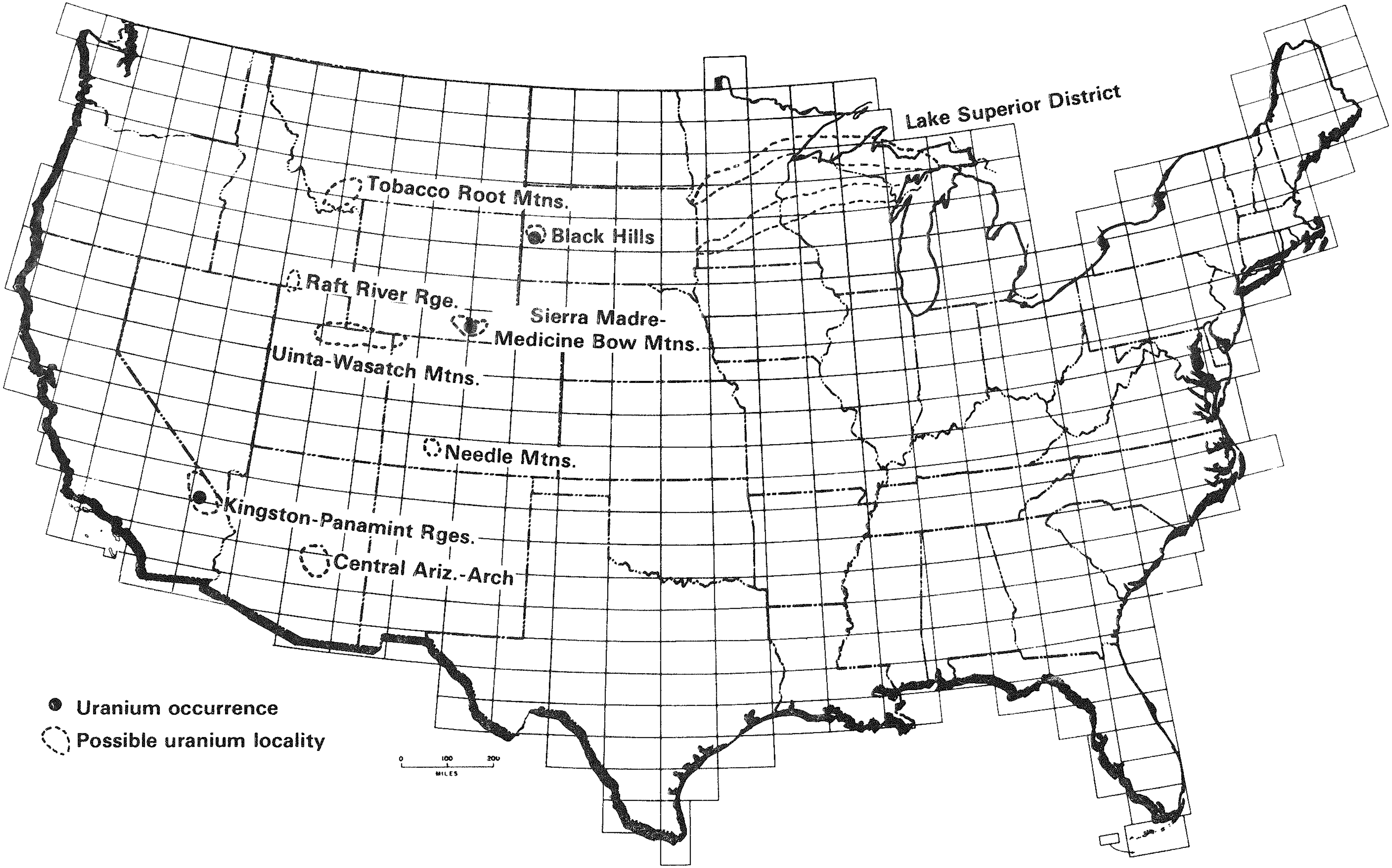
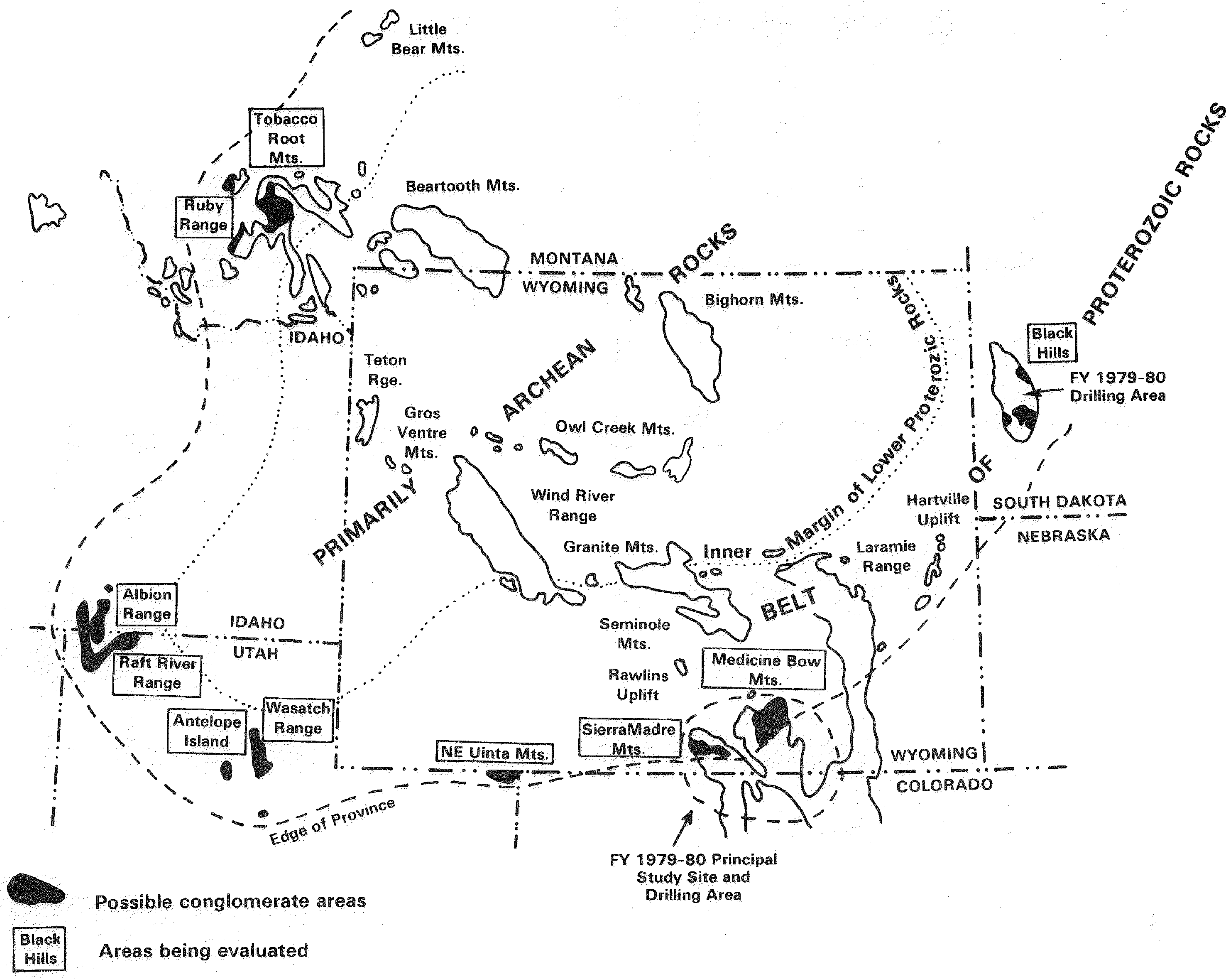


FIGURE 18. *World-class resource studies areas in U.S. favorable for occurrence of uranium in conglomerate*



19. *World-class resource studies—conglomerate in Wyoming sub-province*

Scale 1" = 7.5 mi.

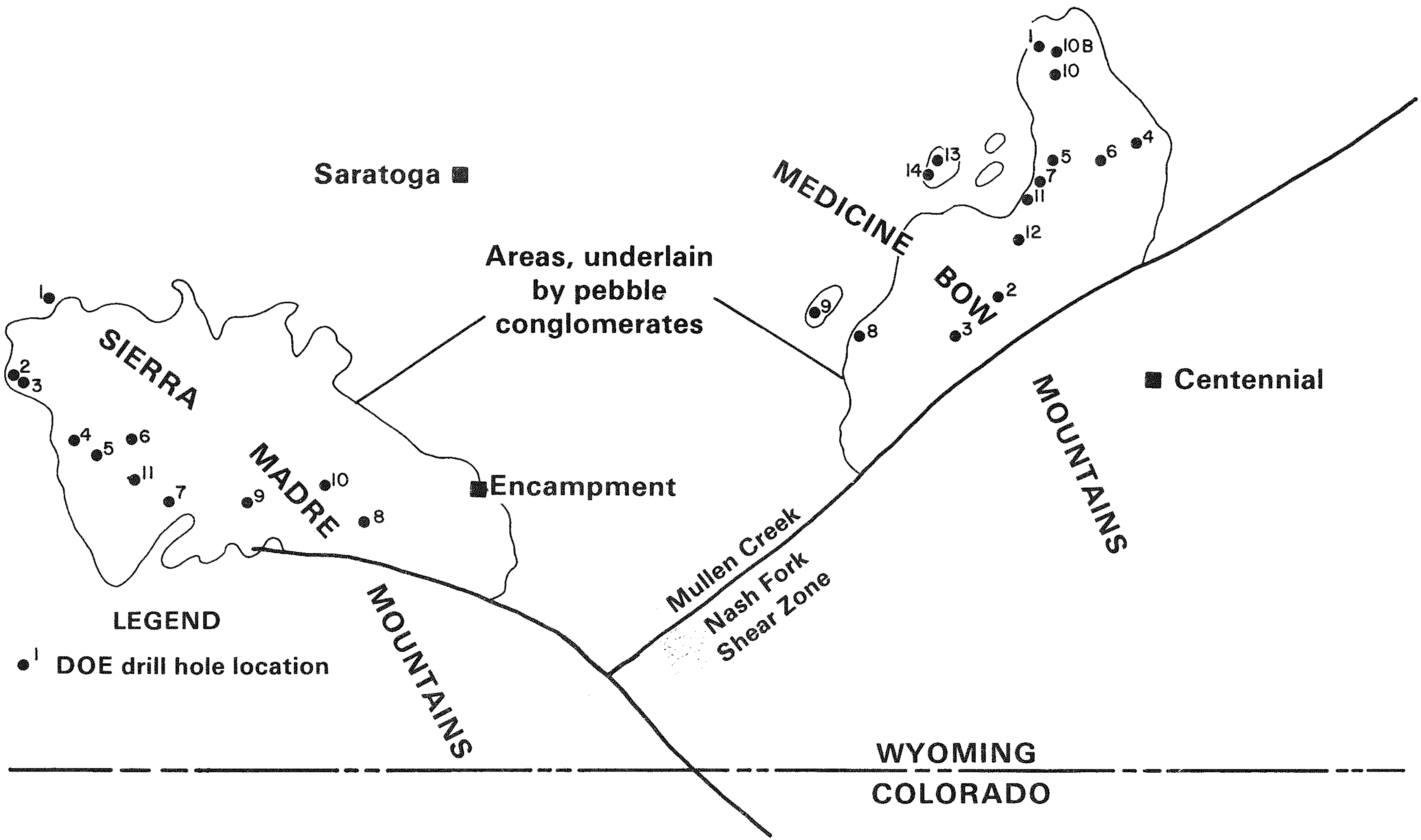


FIGURE 20. *World-class drilling project, southeastern Wyoming site*

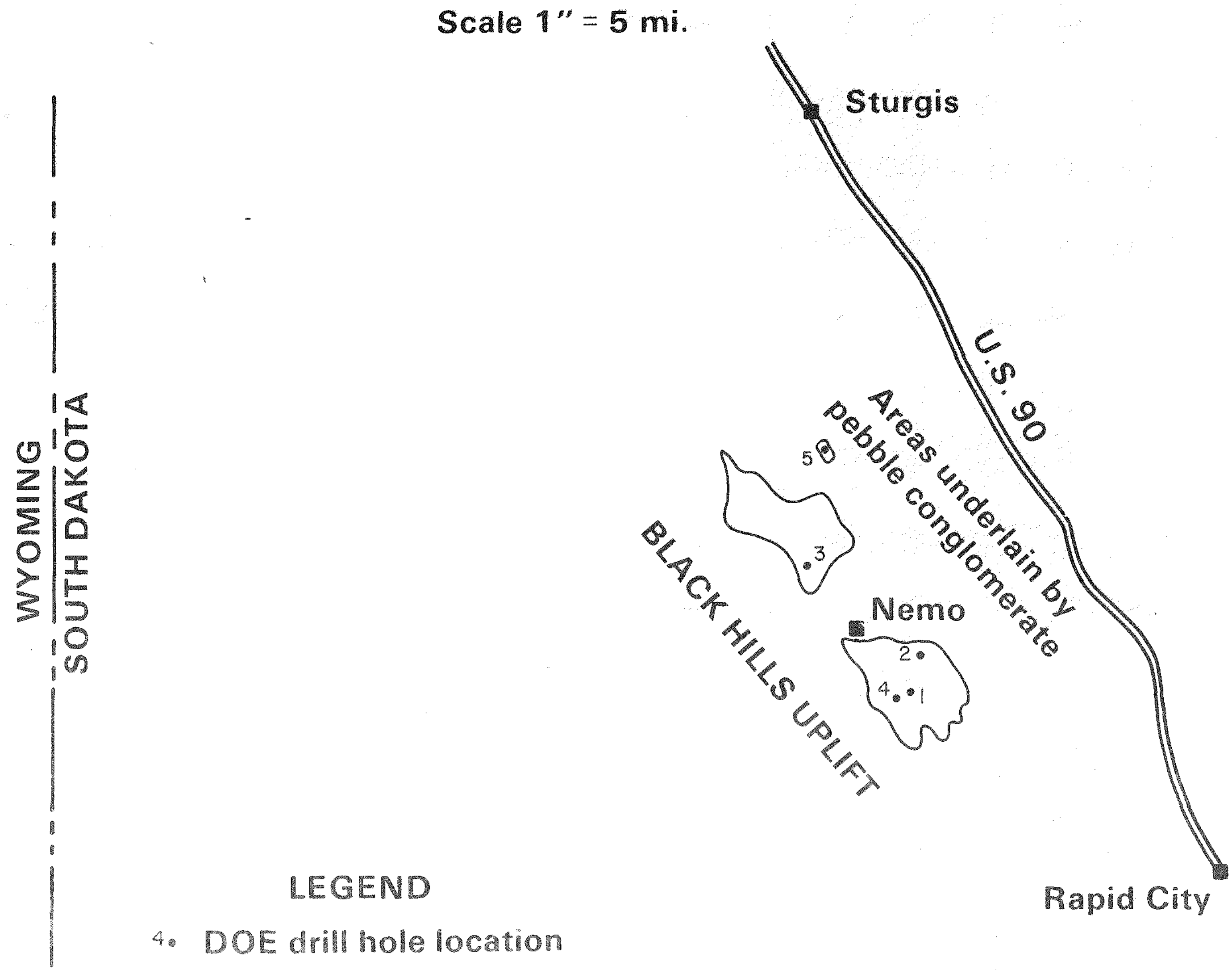


FIGURE 21. *World-class drilling project, Black Hills, South Dakota, site*

2. KUT Probe

- The improved KUT probe has been successfully tested and evaluated. It is routinely used in the NURE program and is expected to be commercialized by about July 1980.

3. New Logging Systems

- The magnetic susceptibility system has been successfully tested and evaluated. It is now being used in the NURE Program.

- A multielement probe-feasibility study was in progress in FY 1979. Prototype testing will start in FY 1980.

- The short optical logging cable (60 m) has worked well. The long optical logging cable (1,500 m) did not work well because of construction flaws. A long cable should be available to the logging industry by 1980.

4. Field Calibration Models

- Gross gamma models at Camp George West, Texas, Grants, New Mexico, and Casper, Wyoming, were deepened to accept longer probes.

- New fission neutron and KUT models have been added at the Texas, New Mexico, and Wyoming model sites.

Aerial Surveying—Notable progress in developing improved aerial surveying technology and in utilizing these improvements on the NURE program was achieved in FY 1979. The following are examples of improvements made for interpretation methods and NURE applications: (1) developing principal components data analysis techniques (routine NURE use), (2) modeling identified problems in treating geologic contacts, (3) establishing a standardized data tape format, (4) developing of spectrum enhancement (MAZE), and (5) utilizing aerial survey data for resource evaluation studies.

The following progress was made in FY 1979 on calibration and quality control of aerial surveys: (1) achieved normalization of aerial radiometric survey data—data now reported in concentration units, and (2) developed, tested, and implemented an aerial surveying data quality assurance program.

Integrated Exploration Systems—This NURE Technology Applications activity has as its long-range goal the development of optimized exploration systems for each major type of uranium deposit in the United States.

During FY 1979 this effort concentrated on the objective of trying to develop an integrated approach for detecting physical and/or chemical "halos" in the host rocks immediately adjacent to known uranium orebodies in the Copper Mountain, Wyoming; Red Desert, Wyoming; Mount Spokane, Washington; and San Juan Basin, New Mexico, test site areas.

FY 1979 concentrated on data acquisition activities, mainly drilling to obtain subsurface samples at strategic three-dimensional locations adjacent to the orebodies. These core samples, along with geophysical and geochemical measurements from the drill holes, will be thoroughly studied in FY 1980.

Logging
- Direct uranium logs—field test, evaluate and transfer PFN and/or DFN technology.
- Improved KUT logs—demonstrate, transfer technology.
- Develop new logs and systems—magnetic susceptibility, multielement, optical cable, etc.

Aerial Surveys
- Demonstrate interpretation and assessment applications—to identify favorable regions, areas, rock units, and possible large low- to intermediate grade occurrences.
- Calibrate, quality control contractor systems.

Integrated Exploration Systems
- Evaluate multiple techniques for halo identification.

FIGURE 22. *Technology applications major objectives FY 1979–1980*

UNITED STATES GEOLOGICAL SURVEY URANIUM AND THORIUM RESOURCE ASSESSMENT AND EXPLORATION RESEARCH PROGRAM FISCAL YEAR 1980

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U.S. Geological Survey
Denver, Colorado

October 1979

INTRODUCTION

Since the major expansion of the U.S. Geological Survey (USGS) uranium-thorium program in Fiscal Year (FY) 1975, emphasis has been placed on studies that link ore-deposit habitat with processes of ore formation and on development of improved geochemical and geophysical exploration techniques. In FY 1980, a multidisciplinary approach to these efforts will continue, with base funding the same as in FY 1979, about $6,600,000. This work and related activities, partly on additional funding from U.S. Department of Energy (DOE), will provide the requisite geologic background for uranium resource estimates of the National Uranium Resource Evaluation (NURE) program in many major uranium areas. No further increase in base program funding is anticipated. Some activities are expected to decrease as outside funding diminishes to reflect the decreasing USGS commitment to NURE and as inflation erodes level funding.

OBJECTIVES AND PROGRAM SCOPE

As stated in the similar paper in last year's symposium proceedings: "The USGS program is designed to improve our understanding of the nature and distribution of uranium and thorium resources of the United States. In studies of known uranium areas we are applying modern concepts of stratigraphy, sedimentation, and igneous and metamorphic petrology, together with modern geochemical and geophysical methods, to obtain new insights into uranium habitat. From these we hope to develop better geologic guides and exploration methods to aid industry in its vital economic role. As basic understanding is improved, we are expanding our work as rapidly as possible to cover frontier provinces of the United States, seeking hitherto unrecognized analogs of known uranium habitats. In particular, increasing attention is being given to investigations of nonsandstone occurrences and promising environments. A major goal throughout the program is to build models of uranium or thorium occurrences which can be used together with area geologic information to improve favorability estimates and resource appraisal for any given potential uranium or thorium habitat."

Research is conducted in six scientific-discipline coordination areas or program elements. Individual projects, their objectives, and annual plans were described in articles in the 1977 and 1978 symposium volumes and in USGS Open-File Reports 77-738 and 78-979. Because most of the 66 research projects continue along the previously described lines, they will not be described again here. Instead, a general rationale and description of research for each program element is presented below.

RESEARCH PROGRAM ELEMENTS

Uranium Geochemistry and Mineralogy

As geologic studies are improving our understanding of ore-deposit habitat and controls on mineralization, geochemical and mineralogic studies are improving our understanding of how the deposits formed—the processes and the sequence in which they acted. Because the ore-forming processes are generally no longer active today, we must find clues to the nature of the original uranium-bearing solutions and the chemical interactions which produced ore and associated alteration through careful study of the minerals themselves and their chemistry in the ore environment. Timing of events is important, because formation of an ore deposit depends on the proper sequence of events linking host rock, source rock, transport of uranium, and deposition of uranium, as well as post-ore events which modify or preserve deposits. Fortunately, powerful tools are available for studying such problems. Electron microprobe work is revealing multiple generations of sulfide and magnetic minerals which record a sequence of chemical changes associated with alteration processes and the formation of uranium-ore deposits in sedimentary environments. Similar studies are showing precise chemistry of ore minerals and new relationships of diverse species of ore minerals spatially associated in ore deposits. New techniques in studying organic materials are yielding insights into the nature and origin of the organic matter which commonly is associated with uranium concentrations, and into the chemical interaction of uranium-bearing solutions and organic matter. Isotopes of carbon, oxygen, and sulfur can be used to trace fugitive chemical processes which acted in the geologic past and to determine such things as temperature of chemical reactions and possible relationship of ore formation to organic or inorganic processes. The aspects mentioned thus far apply to observations around ore deposits, but similar approaches are being applied to studies of granitic and volcanic rocks to examine their fertility as sources of uranium and the mechanisms for removing uranium from them. Uranium and lead isotopes are used to determine ages of ore, host rocks, and source rocks, and to establish how much uranium has been removed from suspected source rocks. All these studies are leading to much deeper understanding of the origin of uranium deposits.

This program element also includes research into and demonstration of geochemical techniques for exploration. Improved equipment for detection of helium, a product of the radioactive decay of uranium, has been developed and its application for analysis of soil gas and ground water demonstrated. Research is probing into the character of geochemical halos developed around ore deposits and into thermoluminescence of minerals affected by the migration of uranium in sedimentary systems. Other work is aimed at better understanding of geochemical sampling of stream sediments and surface, subsurface, or spring waters and interpretation of the resulting chemical data with respect to uranium potential.

Uranium in Sedimentary Environments

Because deposits in sandstone environments dominate the present national uranium-resource scene and many similar undiscovered deposits are presumed to exist, it is of crucial importance to understand their habitats and the controls on mineralization. Research in this program element involves stratigraphy, sedimentology, study of subsurface data, and detailed studies of ore deposits in order to determine the sedimentologic framework and environments of deposition of sedimentary rocks that contain uranium deposits. Study of the ore deposits is aimed at discovering the role of sedimentologic and structural features in the localization of ore. Framework studies at local and regional basin scales are designed to define sediment sources and fluvial depositional systems. Such work involves standard geologic mapping, section measuring, and petrographic examination of the host sedimentary sequences, together with analysis of subsurface drill data. Interpretation critical to deciphering whether or not sandstones are favorable for uranium deposits rest on such subtleties as whether the sands were laid down by meandering or braided streams, and whether mudstones were deposited in long-standing lakes or on flood plains. Porosity and permeability of host rocks commonly seem to be controlling factors in ore concentration; these, in turn, change along or across fluvial-channel deposits, and so the determination of precise conditions and the environment of deposition is essential. On the broader scale of understanding the framework of a whole basin, the investigators must define where the sediments came from and how far and how energetically they were carried before being deposited, and whether or not structures were present during deposition to control sedimentation or formed later, possibly to affect the migration of uranium-bearing ground waters. The sedimentary habitat studies may be abetted by geophysical studies that reveal the third dimension of structure and stratigraphy, and by geochemical studies that give insights into ore-forming processes which may be controlled or influenced by subtle differences in habitat. Studies are being conducted in the San Juan Basin, New Mexico; the Powder River and Wind River Basins, Wyoming; the Denver Basin, Colorado; the Colorado Plateau, Utah and Colorado; the Date Creek Basin, Arizona, and Tertiary basins in Alaska.

Uranium in Igneous and Metamorphic Environments

Important uranium deposits in other countries occur in veinlike bodies near unconformities in ancient Precambrian rocks and in placer concentrations in quartz-pebble conglomerates of Precambrian age. The potential for such deposits in the United States has only recently been recognized. In particular, little has been published on the recently discovered unconformity-related vein deposits, and many questions exist concerning the habitat and origin of these deposits. They are found in Canada and Australia and are the richest in the world. Our studies are aimed at apparently analogous terranes, where we are focusing on comparisons of regional or local geologic settings, petrology, mineralogy, and geochemistry in the poorly understood type areas in Australia and Canada and in selected study areas in the United States, especially in the Great Lakes region.

The understanding of quartz-pebble conglomerate occurrence and their contained uranium deposits is considerably greater than that of the unconformity-related vein deposits, but studies of their resource potential in the United States have barely begun. Field and laboratory research in this program element has recently shown apparent potential for uranium in this habitat in South Dakota and Wyoming and possibilities for extensions of the favorable environment in other western states and the Great Lakes region. Studies of conglomerates to establish their age, source areas, and general favorability for uranium deposits are progressing in all those areas.

In two areas, vein deposits in Precambrian rocks, probably not related to unconformities, are being studied. Other studies are underway on granite-related deposits, in an attempt to understand what kinds of granites in what kinds of settings are favorable for providing uranium to surrounding country rocks and what kinds of granite may contain veinlike or disseminated uranium deposits. Major uranium deposits so far known in volcanic rocks in the United States are limited to caldera environments in Utah and Nevada and to beryllium tuffs in Utah. These are being studied in order to define the settings for mineralization and the general favorabilities of the environments.

The favorability and rather preliminary studies described above are forerunners of planned studies designed to answer fundamental questions of habitat, age, and mineralizing processes. For example, it is not certain whether or not the rich unconformity-related deposits must be of Precambrian age. If they can be younger—that is, if the Precambrian did not provide the only time in which the unknown processes were active—then many other unconformity environments in the United States may have resource potential. Because the source of the uranium, the mineralizing processes, and the concentrating mechanisms are not well understood or even known at all for these deposits, much work is to be aimed at the petrology and geochemistry in order to confront such problems. It will be necessary, if possible, to study the foreign deposits to establish a base of knowledge. Similar problems abound concerning uranium in other igneous and metamorphic environments, and again the approach will require a detailed understanding of the mineralogy, petrology, and geochemistry, the geologic settings, and the timing of events that affected mineralization.

Studies are being conducted in the Reading Prong–Hudson Highlands area, the Adirondacks, New England, the southern Appalachians, the Great Lakes region, Wyoming, the Front Range in Colorado, and volcanic environments of the Basin-Range province. A major part of the research is sponsored by DOE in its "world-class" deposit investigation thrust.

Geophysical Techniques in Uranium and Thorium Exploration

In many habitats of uranium or thorium deposits, geophysical methods are useful either in defining the favorable habitat itself (such as channel sands, rock facies, intrusive bodies, rock contacts, and structural zones) or in detecting geochemical anomalies associated with uranium and thorium or with alteration around an orebody. Research in this program element involves testing and demonstration of ground, aerial, and drill-hole techniques. New methods of direct drill-hole measurement of uranium and its disequilibrium with daughter products, and of display and interpretation of data from aerial radioactivity surveys have been pioneered, and a new instrument for gamma-ray surveys has been developed. In nonradiometric methods, field and laboratory measurements have been used to develop new instrumental and interpretive techniques for detecting possible exploration targets. Both surface and drill-hole methods offer real potential for guiding drilling and cutting exploration expenses by better focusing on targets and reducing the number of drill holes necessary to find orebodies. Research in exploration techniques, interpretation methods, instrument development, and field applications includes ground and aerial magnetics, gravity, reflection seismology, induced polarization, complex resistivity, electromagntic methods, remote sensing, and gamma radiation methods. The research is conducted in the Branches of

Petrophysics and Remote Sensing, Electromagnetics and Geomagnetism, Regional Geophysics, and Isotope Geology.

Uranium Resource Assessment

Most uranium resource assessments have utilized qualitative comparison of unexplored areas with areas of known production. One or more experts simply consider those geologic features believed to influence or control ore concentration in the control area and in the area being assessed and then subjectively assign comparative values for resource potential. The more that is known about the geology and the ore deposits (if any) in both areas, the more confidence can be attached to the estimates. Research in assessment methods is focusing largely on two aspects: models of different types of uranium occurrence, and relatively objective calculations based on measurements and weighting of geologic parameters associated with known ore deposits. Models draw together what is now known about each kind of ore occurrence in a separate habitat, using almost all observable geologic parameters believed to bear on the localization and formation of ore deposits and using inferences of what these parameters mean in the genesis of deposits. Questions are formulated by which assessment areas can be judged against model control areas. Attempts to make the calculation of resource potential more objective will depend on large amounts of data now being collected on major ore districts and whether or not these data show a reliable relationship between measured geologic parameters and the presence, size, and grade of uranium deposits. This work has just begun, sponsored in part, by the DOE. Even if resource assessment proves always to be a subjective judgment, there seems little doubt that the masses of raw geologic information being collected on uranium deposits and on geologic environments of apparent potential will provide a more reliable framework for the necessary subjective judgments.

Thorium Investigations and Resource Assessment

Research in this program element is intended to expand our knowledge of thorium resources beyond the relatively well-known vein and placer deposits. Petrologic and geochemical studies are focusing on disseminated deposits in volcanic rocks, on explosion breccias in a pipelike feature, on thorium associated with rare-earth elements in carbonatites, and on possible hosts in the alkaline suites of igneous plutonic rocks. For the past 2 years, estimation of thorium resources, sponsored by DOE, has dominated activities of the program element.

SELECTED NOTEWORTHY RESULTS OF FY 1979 RESEARCH

Uranium-bearing solutions that formed roll-type ore deposits as in Wyoming appear to have been relatively young meteoric solutions rich in dissolved oxygen. A fairly large reducing capacity in the host rock was required to remove the dissolved oxygen before uranium could be precipitated. In contrast, solutions that formed deposits of the Uravan type had probably lost their dissolved oxygen by slow reactions with ferrous-iron minerals long before ore deposition and so did not require a large reducing capacity in the host rock at the site of ore deposition (H. C. Granger and C. G. Warren).

Geochemical study of a Colorado Plateau lenticular orebody indicates constraints on the mechanism of ore formation. The deposit formed early in the post-depositional history of the Salt Water Member of the Morrison Formation at an interface between flowing ground water containing the ore elements and an underlying stagnant ground water containing reducing agents. The ground-water flow-path is marked by a zone in the host rock from which sodium, potassium, and magnesium were leached, and a sharply defined interface separates this leached zone from the ore zone. The ore is characterized by vertical zonation of selenium, uranium, vanadium, and molybdenum (M. B. Goldhaber and D. J. Carpenter).

Most uranium occurrences in the Basin and Range province of southwestern Utah lie on or near an aeromagnetic high, which also underlies the east-northeast-trending Pioche-Tushar mineral belt. This magnetic high probably reflects a composite of shallow intrusives of Cenozoic calc-alkaline parentage but also reflects a later Cenozoic extrusion of a bimodal basalt-rhyolite suite. Uranium seems most closely related to alkalic rhyolite in the latter suite (C. S. Bromfield).

Geologic study of about 360 square kilometers in the Lakeview uranium area, Oregon, and reconnaissance of adjoining areas have established a regionally extensive Cenozoic volcanic stratigraphy and at least three principal episodes of peraluminous silicic intrusive activity (31–33 m.y., 14–15 m.y., and 7–8 m.y. ago). Of the three episodes of intrusive activity, uranium mineralization appears to be restricted to the two younger episodes and probably associated with the youngest episode (G. W. Walker).

Tertiary basins of the Western United States that contain arkosic alluvial and tuffaceous lacustrine rocks are proving to have large tonnages of low-grade uranium (0.10 percent U_3O_8); this uranium occurs principally in distal alluvial or lacustrine turbidite facies either rich in carbonaceous detritus, where depositional environments were moderately wet, or in highly altered tuffaceous (silicified or zeolitized or both) sediments, where environments were more arid. Further concentration to higher grades (0.10 percent U_3O_8 or better) appears to have required unusual conditions such as an active hydrothermal system associated with a caldera (J. K. Otton).

Major present-day valleys traversing the Laramie Mountains are aligned with major uranium-bearing paleo-channel-sand bodies in the Powder River Basin, suggesting that Eocene streams carried granitic debris from an eastern Granite Mountains source through the Shirley Basin and northward across the Laramie Mountains into the Powder River Basin (D. A. Seeland).

Sedimentologic studies of the Morrison Formation in southern Utah suggest that the lacustrine-humate model for uranium mineralization can be used in favorability studies and resource assessment. Prediction of favorability is based on integrating sedimentologic parameters that indicate the state of fluvial energy regimes and the configuration of growing structures, two features that are essential parts of the model. The model can be used for resource assessment because it can be quantified within reasonable limits to help define potentially mineralized ground, to help delineate areas unfavorable for mineralization, and especially to indicate unfavorable rock units that superficially appear favorable for mineralization (F. Peterson).

Experimental study of uranium partitioning between silica-gel precipitates and uranium-bearing solutions indicates that at pH's and total dissolved carbonate concentrations of typical ground water, secondary silica precipitates may contain 500 to 1,000 times the uranium concentration of coexisting solutions (R. A. Zielinski).

Lead isotope work confirmed that uranium mineralization of Precambrian conglomerates in the northern Medicine Bow Mountains, Wyoming, is of early Proterozoic to late Archean age. Both uranium and thorium moved around in these conglomerates to a significant degree during their later geologic history (F. A. Hills, R. E. Zartman, and H. Hassan).

Field and petrographic studies combined with geochronologic work substantiate earlier inferences of common genetic aspects among the stratabound iron oxide-iron sulfide-uranium oxide occurrences in the northern New Jersey Highlands and southern Hudson Highlands. There are, however, significant differences in the oxide-phase assemblages that suggest differences in the f_{O_2} and perhaps temperature-pressure histories of the deposits. For example, at the Ringwood mines, New Jersey, uraninite is in contact with hematite containing exsolution lamellae of ilmenite; and at the Phillips mine, New York, uraninite is in contact with magnetite, which itself is in contact with ilmenite laths (R. I. Grauch, C. J. Nutt, and K. R. Ludwig).

Two new uranium occurrences were reported from southeastern Alaska. Samples containing as much as 0.13 percent beta eU were collected from the Tertiary Kootznahoo Formation east of Kadake Bay on Kuiu Island. Uranium was also found in uraniferous phosphate in Permian beds near Big John Bay on Kupreanof Island (K. A. Dickinson).

Surface ore trends in the Poison Canyon sandstone, an economic unit in the upper part of the Morrison Formation in the San Juan Basin, New Mexico, correspond with a distinct facies in the underlying "K" shale (a term used by industry to denote a prominent marker bed in the Brushy Basin Member). Mineralization of the sandstone seems to occur only where the unit is underlain by an offshore-lacustrine, gray, pyritic mudstone facies of the "K" shale. Where the mudstone grades laterally into a nearshore-lacustrine red mudstone facies, the overlying Poison Canyon sandstone is barren of uranium. These relationships are consistent with mineralization by the processes proposed in the lacustrine-humate model, suggesting that this model may be applicable in the Grants mineral belt (C. Turner-Peterson).

Consideration of available chemical data shows that, upon cooling of a hydrothermal solution to about 200° C, kinetic factors prevent SO_4 from acting as an oxidizing agent, but H_2S remains an active reducing agent. This disruption of the balance between oxidizing and reducing agents due to kinetic factors related to cooling may cause the reduction and precipitation of uranium in low-temperature, hydrothermal vein-type deposits (C. S. Spirakis).

Studies for the NURE Flagstaff 2-degree sheet have shown 20 diatremes in the Hopi Buttes area that have radioactivity exceeding five times background in the lacustrine limestones and siltstones (K. J. Wenrich).

Iron disulfide (FeS_2) minerals in host rocks for roll-type uranium deposits that contain fossil vegetal matter differ in abundance, distribution, texture, and sulfur isotopes from FeS_2 minerals in host rocks for deposits that do not contain organic matter. Consideration of geochemical conditions that favor pyrite formation (such as bacterial control on pH and sulfur speciation) suggests that bacterial sulfate reduction provided sulfide for ore-stage pyrite in deposits that contain organic matter. In contrast, abiologic sulfur transformations (involving elemental sulfur) favor ore-stage marcasite in deposits that do not contain organic matter. The contrasting origins of ore-stage FeS_2 minerals in host rocks with and without organic matter suggest that previously proposed biogenic and inorganic theories on the origin of roll-type deposits are both valid (R. L. Reynolds and M. B. Goldhaber).

Geochronologic analysis of samples from the Felder and McLean mines in south Texas defined a good isochron for the apparent age of mineralization as 5.1 ± 0.1 m.y. This represents only the time when roll-front migration ended, so extensive earlier mineralization is not ruled out. Remobilization of uranium since 5.1 m.y. ago seems not to have taken place to a large degree, despite indications of this from disequilibrium studies on other deposits. The isochron age may relate either to initiation of fault leakage of H_2S, which was the reductant in ore formation, or to changes in level and direction of ground-water movement in response to changes in sea level (K. R. Ludwig).

Helium surveys in the area of a 70- to 90-meter-deep uranium deposit in south Texas showed a soil-gas anomaly over the orebody. In ground water, helium values defined a larger, generally anomalous area, with radon as a more precise indicator of the deposit itself (G. M. Reimer).

Nonlinear complex-resistivity effects, each reflecting specific chemical reactions, may occur when high electrical currents are applied to natural geologic materials. This fact is being taken advantage of through use of a specially designed borehole probe, with the result that direct downhole identification of some specific mineral species has been achieved (G. R. Olhoeft and J. H. Scott).

Tests using sedimentologic and stratigraphic data on the Salt Wash Member of the Morrison in Red Rock Valley (San Juan Basin, New Mexico) and in the Henry Basin (Utah) suggest that areas unfavorable for uranium deposits can be defined. Data from mineralized control areas plot differently on ternary diagrams than do data from apparently barren areas. Where measured sections or drill core are available, the parameters used are percent cross-bedded sandstone, percent parallel-bedded sandstone, and percent mudstone-claystone. Where only electric-log data are available, the parameters used are sandstone-mudstone ratio, average thickness of sandstone, and number of alternations of sandstone and mudstone (A. C. Huffman and A. R. Kirk).

PARTICIPATION IN THE DEPARTMENT OF ENERGY PROGRAM

USGS work on the NURE program will continue in FY 1980, with completion of favorability evaluation of 23 NTMS (National Topographic Map Series) 2-degree quadrangles. USGS geologists will work with DOE resource-assessment personnel in determining estimated values for geologic parameters used in the resource-assessment equation. The 23 quadrangles are Gallup, Shiprock, Albuquerque, Aztec, Socorro, Flagstaff, Cortez, Moab, Escalante, Salina, Price, Richfield, Delta, Pueblo, Denver, Greeley, Torrington, Newcastle, Gillette, Ekalaka, Craig, Vernal, and Walker Lake. When favorability evaluation of these quadrangles is completed, the USGS will continue in the quadrangle part of the NURE program only in the Iron River 2-degree sheet. Other NURE studies that will continue, at a lower level of funding than in FY 1979, are focusing on nonsandstone settings ("world-class" deposit environments). Work is underway in the Great Lakes region, the Reading Prong, New England, the Adirondacks, quartz-pebble conglomerate localities in Idaho and Montana, and selected caldera systems of the Basin-Range province. DOE sponsorship of thorium resource assessment by the USGS terminated at the end of FY 1979.

NURE QUADRANGLE EVALUATION AND ASSESSMENT

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October 1979

INTRODUCTION

Quadrangle evaluation, for the purposes of the National Uranium Resource Evaluation (NURE) program, comprises those data-collection activities that attempt to identify and quantify certain geologic characteristics of individual quadrangles through use of geophysical, geochemical, and geologic field methods. Quadrangle assessment is concerned with assessing the results of quadrangle evaluation to determine the potential uranium resources of the quadrangle in terms of estimated tons and average grade of U_3O_8.

The overall objective of quadrangle evaluation and assessment is to produce estimates regarding the location and quantity of uranium resources in the United States. Although the objective is easily stated, its accomplishment is another matter. Experts in the fields of geology and statistics have many differing opinions concerning the manner of execution and the reliability of the results of every phase of the program. These opinions have been and will continue to be considered in the planning and execution of the NURE program.

Total truth regarding the locations and extent of any mineral resource can never be known. Additional resources will always be found in unsuspected locations or at known locations but perhaps at higher costs of development and production. A resource estimate that exceeds the known reserves cannot be proved inaccurate at the time the estimate is made. Its reliability is in the mind of the user who will judge the estimate to be reasonable, too high, or too low.

It is tempting to adopt techniques that will give "reasonable" results, but "reasonable" to whom and for what purpose? To avoid the confusion of "reasonable" results, the formulation of an assessment methodology should look to the process and not to the results. The techniques should be criticized, as well as the answers, and hopefully, suggestions for improvements will result.

The techniques currently used to make assessments of undiscovered resources are not cast in concrete. Some changes have been made, and some changes will be made as experience is gained in the execution of the programs.

QUADRANGLE EVALUATION

A program the size of NURE must be divided into work elements if it is to be properly scheduled and administered. The basic work units, geographic areas, are the 1-degree-latitude by 2-degree-longitude quadrangles of the National Topographic Map Series (NTMS) at a scale of 1:250,000. The precise number of quadrangles to be evaluated is currently uncertain. More than 600 in the United States are included in present plans.

Organizations having specific knowledge of the geology in certain quadrangles should be encouraged to participate in the evaluation procedure. To that end, a joint working agreement was made with the U.S. Geological Survey, and subcontracts were let to state geological surveys, universities, and private firms.

Nine field offices, each with responsibility for a particular region, were established to support and direct field activities. Table 1 lists locations of the field offices and the number of quadrangles being evaluated (a total of 116 to be evaluated by October 1980) by the various entities involved.

Figure 1 illustrates the general flow of information and support. The Grand Junction Office of the U.S. Department of Energy (DOE) has overall responsibility for execution of the NURE program. Its directives for quadrangle evaluation are carried out by the Geology Division of the Bendix Field Engineering Corporation (BFEC). Geologic studies

TABLE 1. *Quadrangle evaluation schedule summary*

Region	BFEC	USGS	State	Subcontract	Total
I—Spokane	6	0	0	9	15
II—Reno	5	3	2	2	12
III—Casper	8	4	2	7	21
IV—Grand Junction	5	10	1	4	20
V—Albuquerque	7	6	3	2	18
VI—Austin	7	0	6	5	18
VII—Atlanta	2	0	0	1	3
VIII—Pittsburgh	2	0	0	2	4
IX—Anchorage	1	0	0	4	5
Totals	43	23	14	36	116

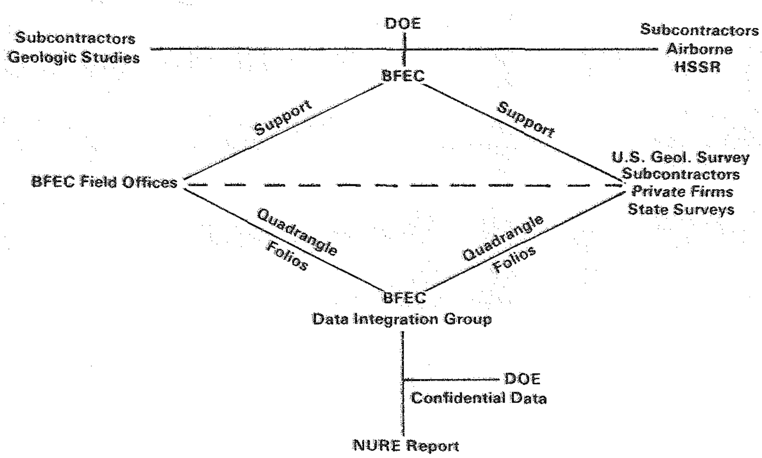

FIGURE 1. *Quadrangle evaluation and assessment*

of a topical nature and the results of aerial and hydrogeochemical surveys are transmitted to BFEC for processing, interpretation, and distribution to the quadrangle evaluators. The end products of quadrangle evaluation are folios, including maps, tables, and texts which contain the information required for assessment. The Geology Division performs the assessments, except for those areas involving company-confidential information; these are assessed by DOE geologists. Final products of the assessments will be released in several NURE reports.

Evaluation Techniques

Quadrangle evaluation (see figure 2) is divided into Phase I (planning), Phase II (field work), and Phase III (folio preparation). These evaluation techniques ensure proper execution of the work and allow management to measure progress. This system is also useful for assigning work, determining budget requirements, and preserving data in the event of departures or reassignments of staff members.

Phase I—Every quadrangle has unique features, and the field work must be carefully planned (see figure 3). It is essential that the field geologist be familiar with the geology of the quadrangle and the availability of data. To this end, the geologist is required to prepare or obtain certain information (see figure 4). There is a need for an annotated list of references, a list of uranium occurrences, and a geologic map. A fourth item, knowledge concerning land status, is required to identify access problems during field work and to determine the availability of uranium resources that may be identified. The fifth item, a work plan, assures that the geologist has a viable plan for evaluating the quadrangle. In smaller organizations, the plan might be

PHASE I -
Prefield work

PHASE II -
Field work

PHASE III -
Folio preparation

FIGURE 2. *Evaluation techniques*

- Access
- Topography
- Geology
- Available information
- Number of samples
- Number of uranium deposits
- Potential favorability

FIGURE 3. *Evaluations tailored to quadrangles*

1. Annotated list of references
2. List of uranium occurrences
3. Geologic map
4. Land status map
5. Work plan

FIGURE 4. *Phase I prefield work*

generated through discussion. However, in the NURE program, some 300 geologists are involved, and more systematic procedures are required.

The objective of the field work which is the identification of areas favorable for the occurrence of uranium has several requirements with which many geologists are unfamiliar, and their reiteration assures compliance. The work plan developed by the geologist prior to field work provides a good measure of how well the requirements are apt to be met; if necessary, redirection of efforts can be accomplished before field work begins.

Phase II—The purpose of Phase II, field work, is to classify geologic environments within the quadrangle as favorable, unfavorable, or unevaluated (see figure 5). Favorable environments are those environments capable of acting as host to the occurrence of at least 100 tons U_3O_8 with an average grade not less than 100 ppm U_3O_8. The 100-ton limit was established to eliminate those environments that are believed to contain little or no resources. The 100-ppm limit was established to eliminate from quadrangle assessment those environments that may contain large quantities of uranium but of very low grade, such as the Chattanooga Shale. Unfavorable environments are those lacking the geologic characteristics judged necessary for the formation and preservation of uranium deposits. Unevaluated environments are those that cannot be adequately evaluated because of lack of information. Use of this last classification is discouraged as it defeats the purpose of the NURE program.

Consistency and uniformity in geologic interpretation, classification, and presentation are essential if the results of the evaluation are to be useful in a standard assessment procedure. The intent of uniformity is not to constrain a geologist's judgment because diversification in evaluation is valuable from a statistical standpoint. Instead, the intent is to give the geologist a foundation and general plan upon which to build his/her case for declaring environments favorable or unfavorable.

To accomplish uniformity and consistency, we have prepared several documents for use by the field geoligist (see figure 6). The first document, "A Preliminary Classification of Uranium Deposits," was a classification of uranium deposits. The resource-assessment methodology required comparison of areas to be assessed with control areas which have known mineralization and usually are producing uranium districts. A classification of uranium deposits provided the most convenient framework for selecting control areas and making comparisons. The guiding philosophy in developing the classification was to provide the most useful framework for assessment. Although the classification are basically genetic, a deposit whose origin has not been convincingly resolved was classified by observable geologic features rather than inferred origin.

A second document, "Geologic Characteristics of Environments Favorable for Uranium Deposits," was prepared to supply detailed information concerning favorable environments. It is organized by class of deposit and contains complete descriptions of every identified class of uranium deposit and specific referenced publications.

The third document, "Preliminary Recognition Criteria for Uranium Occurrences: A Field Guide,"

PURPOSE - CLASSIFY

1. Favorable environment
2. Unfavorable environment
3. Unevaluated environment

FIGURE 5. *Phase II field work*

1. A Preliminary Classification of Uranium Deposits; GJBX-63(78)
2. Geologic Characteristics of Environments Favorable for Uranium Deposits; GJBX-67(78)
3. Preliminary Recognition Criteria for Uranium Occurrences: A Field Guide; GJBX-32(79)

FIGURE 6. *Quadrangle evaluation guides*

is a small field manual of a style and content convenient for field use. It contains summary descriptions of each class of deposit.

Reconnaissance geology is a difficult type of field geology. It requires generalists as opposed to today's trend toward specialists. Many rock types, many structures, and many forms of mineralization are encountered. To be effective, the field geologist must be supported by analytical facilities. To aid the geologist, a competent staff of chemists, mineralogists, and petrographers, and associated laboratories are maintained in Grand Junction. Commercial laboratories are also used when necessary. Data from aerial radiometric surveys, hydrogeochemical surveys, and selective drilling are provided to the field geologists to enable them to do the best job possible in evaluating quadrangles. The various types of general data supplied for the classification of environments are listed in figure 7. The field geologist, the final arbiter of data and its interpretation, describes the favorable environment (see figure 8) in a manner that will allow assessment of the potential uranium resources likely to be present.

- Hydrogeochemical surveys
  - Surface waters
  - Ground water
  - Stream sediment
  - Dry sediments
- Airborne survey
  - Radiometric
  - Magnetic
- Field geology
- Topical studies
- Modeling studies
- Classification and recognition criteria

FIGURE 7. *Data*

Phase III—Phase III work includes the drafting of maps, preparation of tables, and writing of text—components of the quadrangle folio. Figure 9 is a general listing of the contents of a quadrangle folio. To ensure uniform presentation of findings, a style manual has been prepared and distributed to every NURE geologist. A uniform format facilitates the assessment, editing, and review of the folio, and not least of all, the usefulness of the folio to mining companies.

One folio, the Plainview Quadrangle, has been open filed. Others will follow. Present plans call for open filing the 116 folios, which are now in preparation, during 1980 and 1981.

QUADRANGLE ASSESSMENT

There are four categories of uranium resources: reserves and probable, possible, and speculative potential resources. Assessment of speculative resources is the most difficult task with regard to geologic and statistical problems because there are few "truths" upon which to rely. The balance of my comments will be restricted to the assessment of speculative resources.

Speculative potential resources are those estimated to occur in undiscovered or partly defined deposits: (1) in formations or geologic settings not previously productive within a productive geologic province or subprovince, or (2) within a geologic province or subprovince not previously productive.

René Descartes (1596–1650), the father of modern philosophy, gave advice that fits the technique selected for the assessment of potential resources: "It is truth certain that, when it is not in our power to determine what is true, we ought to follow what is most probable." "What is most probable" is the assumption implicit in the selection of the assessment method—additional uranium resources will be discovered in geologic environments similar to those in which known uranium deposits occur, and quantities of uranium likely to be present are proportional to the sizes of the individual endowments. This assumption omits the probability that uranium will be discovered in geologic environments not now known to

1. Projected surface area
2. Depth
3. Thickness
4. Volume
5. Evidence of favorability
6. Class of uranium deposit

FIGURE 8. *Favorable environment*

1. Maps of raw data and interpretation
2. Land status map
3. Composite favorability map
4. Detailed maps of favorable areas
5. Text which describes, for each area:
   —Types of deposits for which area is favorable
   —Specific criteria on which favorability is based, as compared to models
   —Area, volume, and depth of favorable environment

FIGURE 9. *Contents of quadrangle folio*

be favorable. The seriousness of this omission cannot be estimated.

Not every favorable geologic environment will contain uranium deposits, nor will the quantity of uranium present commonly be directly proportional to that of similar environments. Too little is known of the success-versus-failure ratios experienced by exploration groups to allow a statistical determination of the probability that a particular favorable environment contains uranium deposits. The best approach now apparent is to ask the field geologist to estimate, on a subjective basis, the probability of occurrence.

Assessment Methodology

The NURE program imposes two assessment requirements: (1) the estimation of the uranium endowment of the favorable area, and (2) the estimation of the potential uranium resources. Uranium endowment is the total quantity of uranium postulated to exist in concentrations exceeding 100 ppm U_3O_8. Potential uranium resources are those portions of the endowment estimated to be recoverable at selected cost levels.

A control area must have the following attributes: (1) a delineated geographic area, (2) an area with relatively uniform, although not necessarily simple, geologic characteristics, (3) a uranium-producing area or a well-explored area for which data are available concerning the quantity, distribution, and grades of the uranium mineralization present, and (4) an area for which recognition criteria have been determined.

Estimation of the uranium endowment is accomplished by analogy; the favorable area is assumed to contain the same quantity of uranium per unit area, volume, or length as does the control area. The assumed comparison is subject to modification by the assessor.

Equations for calculating the uranium endowment in speculative potential areas are shown in figure 10. The terms "unadjusted" and "adjusted" refer to application of a correction for the fractional part of the favorable area believed to be endowed with uranium as compared to the endowed part of the control area. "Conditional" and "unconditional" refer to the application of a term representing the probability of mineralization. It should be noted that the estimation methodology for speculative potential resources is currently undergoing detailed review, and it is possible that some modifications may result. However, the general concept is expected to remain basically unchanged.

Unadjusted Conditional Endowment

$$U_e = A \cdot d\,(F_c \cdot T_c \cdot G_c) \div 100^*$$

where

U_e = unadjusted conditional endowment

A = area of the favorable area

d = similarity index

F_c = fraction of the control area underlain by the endowment

T_c = tons of rock per unit area of F_c containing the endowment

G_c = average grade, percent U_3O_8, of the endowed rock.

*Division by 100 is required to convert percent U_3O_8 to a fraction.

In practice, all the values have probability distributions representing the uncertainties associated with each value. For ease of discussion, however, these will be treated as single values.

"A," the favorable area, is determined by the field geologist and outlined on a quadrangle favorability map. The value "d," the similarity index, is

Unadjusted Conditional Endowment

$U_e = A \cdot d(F_c \cdot T_c \cdot G_c) \div 100$

Adjusted Conditional Endowment

$U_e - adj = U_e \cdot a_F$

Unconditional Endowment

U_e - uncond. = U_e - adj $\cdot P_o$

FIGURE 10. *Assessment formulas*

determined by the field geologist. The propriety of using "d" is in question as it appears that it may not always represent a totally independent variable. It is usually a fraction between 0.4 and 1.0. It represents the geologist's determination of the degree of similarity, generally with regard to presence or absence of specific recognition criteria, between the favorable area and the control area. Low values of "d" suggest that the wrong control area has been chosen or that the favorable area is, in fact, unfavorable.

The subscript "c" indicates values determined for the control area. "F_c" is that fraction of the control area underlain by endowed rock or, if you will, the mineralized area. "T_c" is the total tons of endowed rock per unit area. "G_c" is the average grade, in percent U_3O_8, of the endowed rock. Division by 100 is necessary to convert percent U_3O_8 to a fraction.

Adjusted Conditional Endowment—In the equation, the uranium endowment of the favorable area is directly proportional to the size of the favorable area as compared to the size of the control area, modified only by the similarity index "d." The impropriety of this forced relationship is recognized. Control-area boundaries are tightly drawn because of available detailed geologic work, whereas favorable areas, generally because of the paucity of subsurface data and uncertain geologic boundaries, tend to be loosely drawn. To be brief, favorable areas are usually substantially larger than control areas. To correct for this, another term, "a_F," fraction adjustment, is used as a multiplier to yield the adjusted conditional endowment (see figure 10). The fraction adjustment is solicited from the field geologist and is a subjective estimate of the expected ratio of the endowed fraction in the favorable area to the endowed fraction in the control area. In assessments made to date, "a_F" has been greater than 0.1 and less than 1.0.

Unconditional Endowment—In classifying an area as favorable, the field geologist has determined that the area, the geologic environment, may indeed contain uranium deposits. The value selected for "d" represents the geologist's best judgment, supported by a comparison of recognition criteria, of the degree of similarity between the favorable area and the control area. The selection of the value for "a_F" allows the field geologist to indicate an opinion as to the probable extent of the mineralization. The values determined thus far have been as rigorously derived as is believed possible, short of extensive drilling in the favorable area. Not having the money or the time required for extensive drilling, it is necessary to return to the most reliable source, the field geologist, for information concerning the possibility of occurrence of mineralization. The value "P_o" is a subjective estimate made by the field geologist of the probability that uranium deposits are present in the favorable area. In assessments made to date, the values given for "P_o" have been greater than 0.1 and less than 0.8.

Not discussed at this time are the many problems associated with soliciting probability values. However, it is necessary to make an estimate of the total potential uranium resources of the United States. To add the individual potential resources of the hundreds of favorable areas requires use of the probability of endowment. Some statisticians, who point out that the estimates will be made by a large number of geologists, suggest that errors will cancel, and the resulting summation will be statistically acceptable.

Potential Uranium Resources—Potential uranium resources are those portions of the endowment that can be recovered at fixed forward costs, presently established at $30, $50, and $100 per pound U_3O_8. The potential resources are determined by assuming that the favorable area has the same grade-tonnage distribution as the control area. This assumption is probably not correct in most cases, but the errors introduced are well below the levels of accuracy of the other factors. The cutoff grade, and therefore the quantity of uranium above the cutoff grade, is determined by applying costs established for the particular mining and milling processes judged to be proper for the favorable area.

CONCLUSIONS

The NURE program effort will continue to generate and employ improvements in assessment technology. Assessment procedures in current use are carefully documented to the extent that a useful "audit trail" is available; these data extend from the actual recording of field observations and identification of favorability areas to the selection of the proper control areas and application to the actual assessment function. BFEC is confident that the basic system of assessment of the unknown by analogy to the known is fully tenable. And, BFEC is proud to be a contributing party to the NURE program which is of a magnitude not hitherto undertaken by any government or private organization.

FOREIGN EXPLORATION AND URANIUM SUPPLY

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Presented by Robert J. Wright

October 1979

INTRODUCTION

The purpose of this paper is to discuss uranium activities in the parts of the world outside the United States.

The first section is devoted to exploration. In previous seminar papers, special attention was given to exploration in Africa (1977), Canada (1976), and Australia (1975). This year the focus is on Latin America where successful exploration has resulted in an increase of reserves in three countries: Brazil, Mexico, and Argentina. Before the discussion of Latin America, however, attention is given to developments in Canada and Australia, which continue to be the most popular countries for exploration and development, apart from the United States.

Following the section on exploration, an update of world uranium resources is provided along with a current estimate of future production in various countries. Unless otherwise specified, tonnages mentioned in this report are indicated as short tons.

CANADA

Exploration in Canada continues at somewhat the same pace as in 1978, when expenditures were reported at $90 million. Over 80 percent of the exploration effort is in Saskatchewan, Northwest Territories, Quebec, and British Columbia. In Saskatchewan, the activity is still concentrated in the southern and eastern margins of the Athabasca Basin, where some 116 companies spent about $45 million in 1978. Other important centers of activity are the Kitts-Michelin area of Newfoundland, the Kelowna-Beaverdell area of British Columbia, and the Baker Lake Basin in the Keewatin district of Northwest Territories.

Athabasca Basin

As new discoveries continue to be made and earlier finds are expanded by drilling, the pace of exploration continues to mount. Chief interest is the area around Midwest Lake and Rabbit Lake at the eastern end of the Athabasca Basin (see figure 1).

At Rabbit Lake, production by Gulf-Uranerz commenced in 1975 at 430 tons U_3O_8, and increased to 1,800 tons in 1976, 2,570 in 1977, and 2,750 in 1978, exceeding the originally announced capacity of 2,250 tons U_3O_8. Gulf reports that 1978 drilling on the Collins Bay deposit, located to the north of the Rabbit Lake mine, indicates a high-grade orebody of significant size. Production is planned for the early 1980s.

At Midwest Lake the reserves have recently been quoted at 56,000,000 pounds U_3O_8 at an average grade of 1.25 percent U_3O_8.

New discoveries have been made on the ground between Rabbit Lake and Midwest Lake, held primarily by Asamera-Kelvin and Canadian Occidental-INCO.

Occidental-INCO recently reported intersections of 33 feet containing 27 percent U_3O_8 and 17 feet containing 12 percent U_3O_8. Possible dimensions of an orebody have not been reported for this site 7 miles west of Rabbit Lake and 9 miles east of Midwest Lake.

Asamera Oil-Kelvin Resources holds land surrounding Midwest Lake. The main centers of interest are Dawn Lake and the Hole No. 11 area, where uranium has been discovered over lengths of 1,500 feet and 1,800 feet. At Dawn Lake, thicknesses of up to 72 feet containing 5 percent U_3O_8

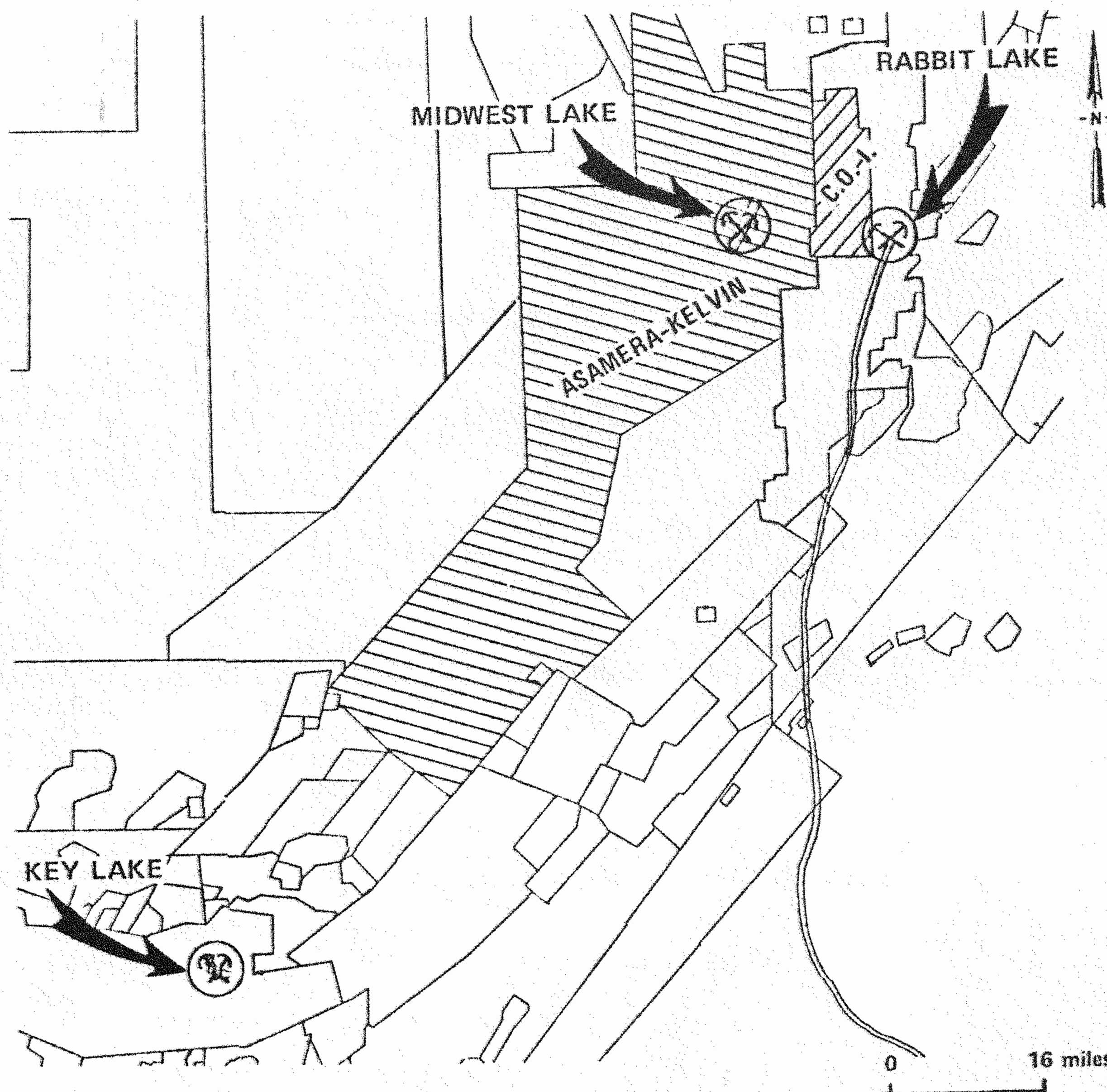


FIGURE 1. *Eastern part of Athabasca Basin, Saskatchewan*

have been encountered. At Hole No. 11, up to 11 feet of over 17 percent U_3O_8 have been drilled. Much more exploration will be required to determine the true dimensions of the ore zones.

Labrador

In Labrador, Brinco Ltd., a firm owned by Rio Tinto, Urangesellschaft, and Bethlehem Steel, has announced plans to proceed with mine and mill construction at a reported cost of $160 million for the Kitts and Michelin deposits, north of Goose Bay, Newfoundland (see figure 2). A 1982 start-up is planned.

Reserves are:

	Tons Ore	% U_3O_8	Tons U_3O_8
Kitts	259,030	0.57	1,480
Michelin	7,181,000	0.12	8,617
		Total	10,097

The uranium occurs in moderately to steeply-dipping tabular orebodies in folded Proterozoic rocks of volcanic origin. Additional exploration in the Michelin area has found high-grade (6 to 18 percent U_3O_8) uraniferous boulder trains at Melody Lake and Mustang Lake, and bedrock and boulder deposits at McLenn Lake. These occurrences are being drilled this year.

AUSTRALIA

Exploration (see figure 3) has slowed during the past couple of years as companies have waited for government policies toward uranium to be clarified, but now things are again beginning to move. The environmental reports for Ranger and Nabarlek, two of the four large deposits in the Alligator Rivers area of the Northern Territory, have been approved, and construction has started. Although Ranger was the first project approved by the government, it appears likely that Nabarlek will be commissioned first because of the smaller size.

Ranger's No. 1 orebody which contains about 51,000 tons U_3O_8 in 17.3 million tons of ore is being developed as an open-pit mine to a planned depth of 575 feet. Production will start in 1981 at 4,500 tons of ore per day. The mill is to reach design capacity during 1982 with 1,265,000 tons of ore at 0.26 percent U_3O_8 treated annually to produce 3,300 tons U_3O_8.

The Australian government has announced plans to sell part or all of its 50-percent interest in the Ranger operation, and purchase proposals were received in early October. British and Japanese utilities are mentioned as possible purchasers.

Nabarlek was approved for development by the government in March 1979. Although this 10,000-ton U_3O_8 orebody (2.4 percent U_3O_8) received approval later than the Ranger operation, production will probably be attained by late 1980 or early 1981. Reportedly, the ore will be extracted in 2 years, but processing will extend over 8 to 10 years to produce 1,200 tons U_3O_8 per year. Tailings will go into the abandoned pit.

The environmental statement for Jabiluka was filed in late 1977, but the government has not taken final action. In 1979, the company modified its proposal to provide for underground rather than open-pit mining, so that environmental effects would be reduced. Development of the Jabiluka complex will take 3 to 4 years. The plan is to produce 3,300 tons U_3O_8 per year, beginning the fourth year after construction commences, increasing eventually to about 10,000 tons U_3O_8 per year after 5 years of operation. Estimated reserves for mine-design purposes are 108,000 tons U_3O_8, but resources total about 230,000 tons.

The Koongarra deposit contains 5,430,000 tons of ore with about 14,630 tons U_3O_8. Production at 1,100 tons U_3O_8 annually will start 2 to 3 years after government approval is received.

Western Australia

In Western Australia, Western Mining Corporation has reached an agreement with Esso (15 percent) and Urangesellschaft (20 percent) to develop the Yeelirrie deposit. After metallurgical research at the pilot plant near Kalgoorie, the companies plan to develop the mine-mill complex at Yeelirrie for start-up by 1984.

South Australia

An Australian discovery that has attracted great attention is the Olympic Dam prospect on Roxby Downs Station, some 100 miles northeast of Port Auguata in the state of South Australia. Uranium is associated with copper at depths of 1,000 to 2,000 feet. The property is owned by the Western Mining Corporation (51 percent) and British Petroleum (49 percent). Some 20 holes assay 1 to 2 percent copper and 0.01 to 0.20 percent U_3O_8. Figure 4 shows the general configuration of the

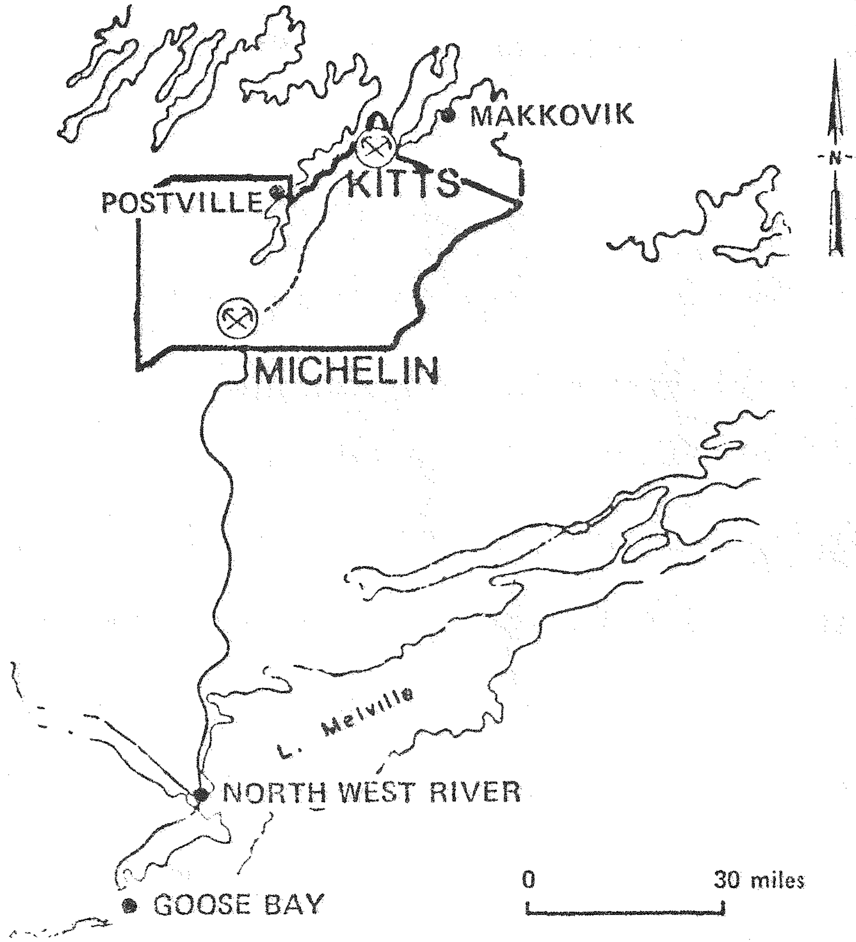


FIGURE 2. *Kitts-Michelin area, Labrador*

drilling to the end of 1978. Only three holes contain one pound of U_3O_8 or more, but all holes show 1 to 2 percent copper. At this grade, uranium alone would probably not support a viable operation.

Although the company has not released reserve data, an unidentified Australian source estimates reserves at 11,500,000 metric tons of copper and 562,500 tons U_3O_8 (World Mining Yearbook, 1979, p. 91).

The deposit, which is reported to be in hematitic granite and breccia, was discovered as a geophysical anomaly. Uranium mineralization occurs with chalcopyrite, bornite, chalcocite, and digenite associated with quartz, sericite, and hematite. Mineralization appears to occur on a basement high overlain by 1,000 feet of sediments.

The position of the state of South Australia has been to oppose mining radioactive material until the problems of nuclear proliferation and waste management are settled on a worldwide basis. However, the Labor government was defeated in a September 1979 election, and uranium mining may now be possible.

Queensland

Minatome Australia Pty., Ltd., is preparing an environmental impact statement for the Ben Lomond property near Townsville. Little information has been released about the deposit, but it is reported to be in Paleozoic acid volcanic sedimentary rocks at less than 500 feet in depth. One source speculates that Ben Lomond might contain 4,000 metric tons U_3O_8.

LATIN AMERICA

Although uranium exploration in various parts of Latin America has been going on since the 1950s, no substantial resources had been reported prior to 1978. Because of the region's large size, its geologic diversity, and its similarity to parts of the

FIGURE 3. *Uranium deposits, Australia*

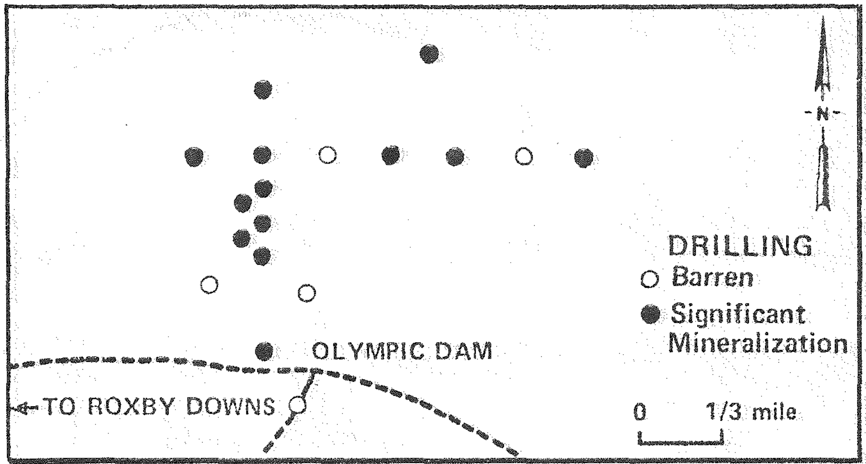


FIGURE 4. *Roxby Downs area, South Australia*

United States and Canada with substantial uranium resources, it has appeared likely that various types of uranium deposits might be discovered.

During 1978 and early 1979, the fruits of successful exploration became evident as increases in reserves were announced in Brazil, Mexico, and Argentina.

BRAZIL

Among Latin American countries, Brazil was one of the hardest hit by the 1973–74 oil crisis. This crisis stimulated a push to develop the country's fledgling, nuclear power program, and in 1975, a multibillion dollar package was signed with West Germany to provide eight nuclear power reactors along with enrichment and fuel reprocessing facilities. Since then the deal has been beset by rising costs and other problems which have tended to stretch out the original time table. Brazil has signed contracts for the first two reactors and letters of intent for the next two, but the fate of the other four is unclear.

To back up its nuclear plans, Brazil, through the national company Nuclebras, has invested in uranium exploration at the rate of $20 to $25 million per year. The results are now beginning to show. The latest estimate issued earlier this year indicates 193,800 metric tons U_3O_8 in reserves, of which 87,500 metric tons are proved and 106,300 metric tons are inferred. These figures indicate a substantial gain over the 142,300 metric tons reported in 1978. In turn, this estimate was twice the 1977 figure of 66,800 tons. Most of the increase has been at Itatira in the state of Ceara, where reserves are now estimated at 122,500 metric tons—more than half of Brazil's total (see figure 5).

Itatira

Itatira is located in an unusual geologic setting and may represent a previously unidentified ore type. The mineralization was discovered in a stream bottom by carborne radiometric equipment which detected radioactive cobbles that were traced several miles upstream to the source.

The deposit forms a hill about one-half mile long and perhaps 300 feet high underlain by limestone of the Precambrian Caico Formation. The mineralization consists of uraniferous collophane (the phosphate mineral) which has replaced the limestone on a massive scale. The uranium is carried entirely within the mineral structure of the collophane, and no uranium minerals are visible. Some drill intersections show a range of values from 9 to 17 percent P_2O_5 and 0.09 to 0.11 percent U_3O_8. The deposit is well situated for open-pit extraction, but the metallurgy may be difficult. However, by-product recovery of phosphate may be possible.

The unmineralized limestone surrounding the prospect is cut by dikes of an unusual rock, composed mainly of albite feldspar that is called "feldspathite" by Nuclebras. Although its relationship to uranium is uncertain, this same rock type contains the uranium mineralization at Espinharas (about 400 miles away), thus providing a geologic link between these apparently different deposits.

FIGURE 5. *Uranium deposits, Brazil*

Espinharas, in the state of Paraiba, is located in the part of Brazil covered by a joint German-Brazilian exploration arrangement. The operating company Nuclam is owned by the Brazilian government (51 percent), and by Urangesellschaft (49 percent). The first discovery was made here in 1972 during a carborne radiometric survey. The mineralization forms a zone 1 to 2 miles long and from one-half foot to 60 feet wide along a major northeast-trending lineament in Precambrian metasediments. This deposit is credited with around 10,000 tons of reserves averaging between 0.06 and 0.2 percent U_3O_8. Most of the uranium is contained in pitchblende with the remainder in a mineral similar to allanite. The mineralization is related to extensive introduction of albite along the lineament, forming feldspathite, which provides porosity that permitted the introduction of uranium.

Some geologists have suggested that this deposit, and Itatira as well, may be similar to the uranium-bearing albitite deposits of the USSR that reportedly contain about 80 percent of the Soviet uranium reserves.

Pocos de Caldas

Nuclebras is on schedule with its first uranium development the Osamu Utsumi open-pit mine and concentrator near Pocos de Caldas. Preproduction stripping began in 1977, and the entire complex should be on stream by the end of 1979. Production is scheduled to be 600 tons U_3O_8 per year over a 10- or 12-year period. Mine production will be 2,500 tons of ore per day at an average waste to ore ratio of five to one. When completed, the open pit is expected to be 900 feet deep and more than one-half mile in diameter.

The deposit is located on the side of a complex caldera structure about 20 miles in diameter (see figure 6). At least fourteen circular structures have been identified; many of these are visible on Landsat images. The volcanism, dated at about 80 million years, cuts Precambrian rocks (Santos, 1978). The uranium occurs as sooty, massive, mainly secondary pitchblende associated with pyrite, fluorite, and molybdenum minerals.

Weathering is deep, and oxidation penetrates to depths of 650 feet or more below the surface. The few outcrops have hindered prospecting; however, the deep oxidation permitted the secondary concentration of uranium which forms much of the ore. The orebodies result partly from redistribution of uranium during oxidation of the volcanics and partly from hydrothermal activity following volcanism.

The ore is contained in three blocks designated A, E, and B (see figure 7). The A-block deposit is one-half mile long, 120 feet wide, and 700 feet deep; it contains 20 percent of the ore reserves. Most of the ore is related to breccia bodies that form dikes which appear to be related to a volcanic pipe. These consist of very fine grained rock fragments containing pyrite, uranium, and molybdenite.

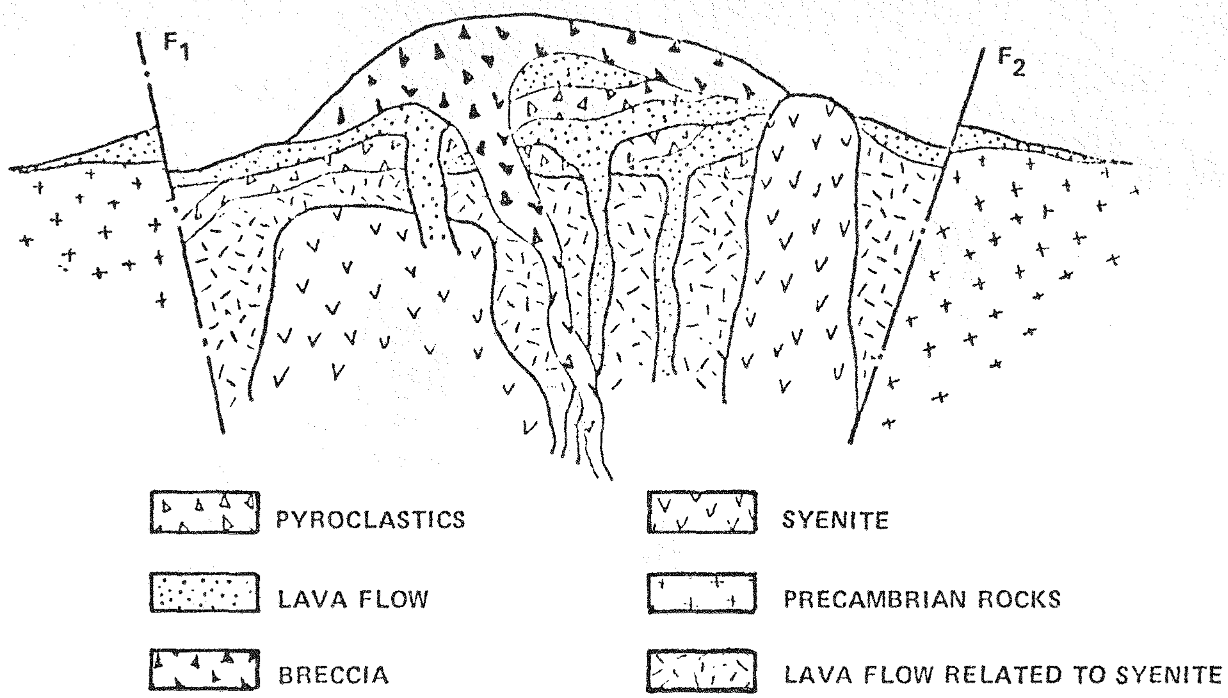
The E block is 3,500 feet long, 1,300 feet wide, and up to 400 feet deep. Uranium occurs entirely in the form of secondary pitchblende which forms a zone of enrichment immediately below the redox interface at the lower limit of oxidation. Here, pitchblende forms both sooty and massive nodules, up to 2 or 3 inches in diameter, consisting of black clay with pyrite. Pitchblende also forms powdery-black patches and veins that look like normal hydrothermal deposits but are believed to be secondary. This block contains about 15 percent of the reserves.

Two-thirds of the reserves are in the B block, one-half mile long, 1,300 feet wide, and 900 feet deep, which is in a pyroclastic unit of volcanic tuff, lava, ash, and breccia immediately outside the caldera margin. The upper part of the ore zone lies immediately below the redox interface and contains nodular pitchblende much like the mineralization in the E zone. The lower part of the ore is believed to be hydrothermal in origin, and the mineralization occupies irregular, flat-lying pods called "amas," a colloquial Portuguese word for potato. The rocks of the B block are the most porous of the entire complex, and this porosity may be the principal control of mineralization.

Mexico

Mexico is the second Latin American country with a changed uranium outlook in 1979.

Through 1977, the Mexican resources were listed as a nominal 11,000 metric tons U_3O_8, but it was known that important discoveries had been made northeast of Chihuahua. During 1979, resources were increased to 9,000 metric tons of proven reserves, 30 to 35,000 metric tons of probable resources and up to 250,000 metric tons of possible resources—a total of nearly 300,000 tons



F_1 & F_2—BOUNDING FAULTS

FIGURE 6. *Idealized cross section, Pocos de Caldas intrusive complex, Brazil*

U_3O_8. During recent months, there have been discussions between the Mexican government and the French Atomic Energy Commission (CEA) concerning a uranium processing plant in Chihuahua and assistance in exploration.

The most important district is Peña Blanca, located about 30 miles north of the city of Chihuahua (see figure 8). The bulk of the economic mineralization is in volcanic ash and tuff representing the fallout from volcanic eruptions that took place 37 to 44 million years ago. The volcanic unit is 600 feet thick and rests on a surface of considerable relief developed upon Cretaceous limestone. Uranium occurs in several geologic settings (Goodell, Trentham, and Carraway, 1978). Some deposits are of a single type, but some of the larger deposits contain more than one type. The environments are described as follows:

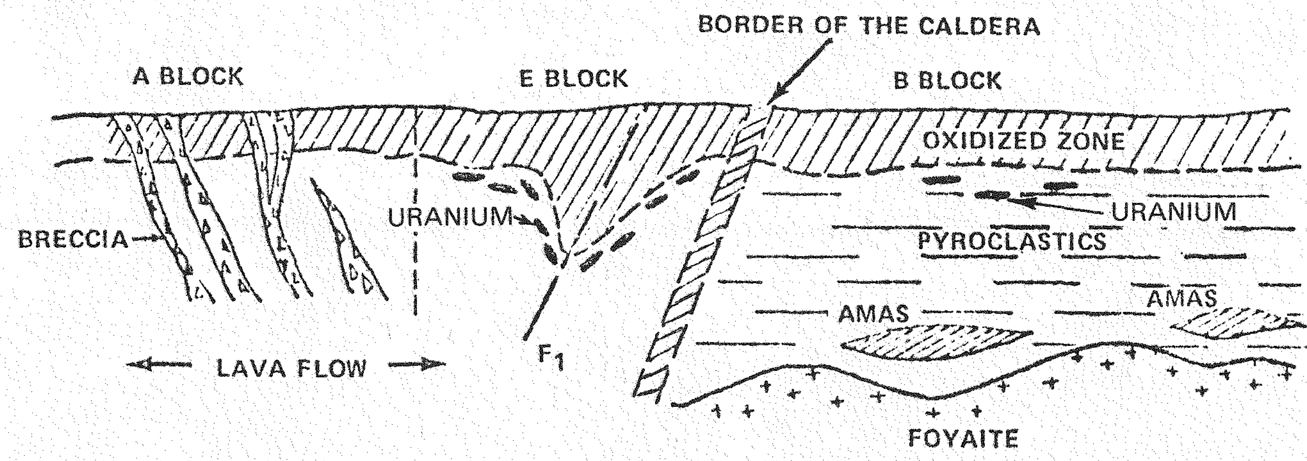
1. Mineralized, steep faults in the volcanic units. Jointing or faulting in brittle, massive rocks provide pathways for solution movement. This environment is typified by Nopal I, a small, high-grade deposit located in a breccia zone at the intersection of two steep faults. In plan, the deposit is a 150-foot by 70-foot oval which extends vertically for over 150 feet. It has reported reserves of 360 metric tons U_3O_8 at an average grade of 0.3 to 0.4 percent U_3O_8 and 0.07 percent molybdenum.

2. Mineralization within porous and permeable units in the volcanic sequence. The more porous beds may contain stratabound deposits.

3. Mineralization at the base of the volcanic unit where the rocks consist of altered glassy layers that are more porous, more permeable, and more chemically active than the surrounding rock.

4. Mineralization of porous pumice at the base of the volcanics.

5. Mineralization in the top of the Cretaceous limestone. Uranium has been deposited in faults, solution cavities, and other permeable zones.



"Amas" refers to potato-shaped uranium concentrations. A-block ore occurs in breccia zones, E-block ore at the base of the oxidized zone, and B-block ore at the base of the oxidized zone and in the "Amas".

FIGURE 7. *Idealized cross section of A-, B-, and E-ore blocks, Pocos de Caldas, Brazil*

The largest deposit known as Margaritas contains mineralization of three different types. Widespread stratabound mineralization has been drilled out at the base of the volcanics (types three and four above), while uranium also occupies fracture and solution cavity fillings in the underlying limestone (type five above). Type three mineralization contains most of the reserves reported to be 4,000 metric tons U_3O_8 with an average grade of 0.2 percent. The deposit is at least 300 feet wide, 10 feet thick, and extends in a northeast-southwest direction for more than 1 mile.

Most other Mexican reserves, outside the Chihuahua area, are in the eastern coastal plain near the border between the states of Tamaulipas and Nuevo Leon. Two deposits are known, and the geologic setting is apparently similar to that in the Texas Coastal Plain.

Argentina

Uranium exploration has been conducted in Argentina for more than 20 years. Various types of deposits have been found in several portions of the western border of the country (see figure 9), but most of the ore is in sandstone. Since the late 1960s, uranium production has averaged 180 metric tons per year of uranium from concentrators in three locations: Malargüe (Mendoza province, 70 metric tons), Don Otto (Salta province, 50 metric tons), and Los Adobes (Chubut province, 60 metric tons). The production at Malargüe is being doubled to 130 metric tons per year.

Argentina's Atomic Energy Commission (CNEA) has been accepting prequalification bids for firms to finance development and operation of a uranium mine and mill at Sierra Pintada (Mendoza province) where reserves are estimated at 16,000 metric tons U_3O_8. Mine development and construction to produce 700 metric tons of U_3O_8 per year from 1,200 to 2,000 tons of ore per day will cost about $60 million.

In late 1979, a sulfuric acid plant in Southern Mendoza Province is expected to produce 180,000 metric tons of sulfuric acid per year, about half of which will be used in the new Sierra Pintada uranium facility.

WORLD URANIUM RESOURCES

Uranium resources at $30 and $50 per pound U_3O_8 for the western world are shown in table 1. According to the International Atomic Energy Agency's definitions, "reasonably assured resources" refers to uranium that occurs in known mineral deposits of such size, grade, and configuration that they could be recovered within given cost ranges using current mining and milling technology. This corresponds, more or less, with DOE's reserve category. "Estimated additional resources" refers to uranium expected to occur in exten-

FIGURE 8. *Uranium deposits, Mexico*

TABLE 1. *World uranium resources by continent*
(Excludes Peoples Republic of China, USSR, and Associated Countries)
(Thousand tons U_3O_8)

	Reasonably assured		Estimated additional	
	$30/lb U_3O_8	**$50/lb U_3O_8***	**$30/lb U_3O_8**	**$50/lb U_3O_8***
North America	**980**	**1,270**	**1,530**	**2,510**
U.S.	690	920	1,010	1,505
Canada	280	305	480	945
Mexico	9	9	44	44
Greenland	0	35	0	21
Africa	**790**	**1,000**	**180**	**340**
South Africa	320	508	70	180
Niger	210	210	69	69
Namibia	152	173	39	69
Algeria	36	36	0	7
Gabon	48	48	0	0
C.A.E.	23	23	0	0
Zaire	2	2	2	2
Somalia	0	6	0	3
Egypt	0	0	0	7
Madagascar	0	0	0	3
Botswana	0	0.5	0	0
Australia	**380**	**390**	**60**	**70**
Europe	**90**	**510**	**60**	**130**
France	51	72	34	60
Spain	13	13	11	11
Portugal	9	10	3	3
Yugoslavia	6	8	7	27
United Kingdom	0	0	0	10
Germany	5	5	9	10
Italy	0	2	0	3
Austria	2	2	0	0
Sweden	1	390	0	4
Finland	0	4	0	0
Asia	**50**	**60**	**0**	**30**
India	39	39	1	31
Japan	10	10	0	0
Turkey	3	5	0	0
Korea	0	6	0	0
Philippines	0.4	0.4	0	0
South America	**130**	**130**	**130**	**140**
Brazil	96	96	117	117
Argentina	30	36	5	12
Chile	0	0	7	7
Bolivia	0	0	0	0.9
Total (Rounded)	**2,400**	**3,400**	**2,000**	**3,200**

*Includes resources at $30/lb U_3O_8

Source: Modified from "Uranium Resources, Production and Demand," OECD Nuclear Energy Agency and the International Atomic Energy Agency, December 1977.

sions of explored, little explored, and undiscovered deposits along well-defined geologic trends with known deposits. This category corresponds, more or less, with DOE's probable potential resources. Figures 10 and 11 show the global distribution of "reasonably assured and estimated additional resources" at $30 per pound U_3O_8.

As previously described, significant increases have been reported in Latin America during the past year as a result of exploration in Argentina, Brazil, and Mexico. In addition, reserves for India have increased from 5,000 tons to nearly 40,000 tons U_3O_8 as a result of continuing exploration.

Foreign Production Capability

Producer nations have reviewed current and planned uranium production at the request of the Nuclear Energy Agency and the International Atomic Energy Agency (see table 2). In the early 1980s, production is expected to increase markedly as Australian production in the Alligator Rivers area comes on stream and as deposits under development in Canada and in Niger begin production. Also, South Africa expects to expand byproduct uranium recovery from gold mining.

As table 2 indicates, foreign production probably will reach about 33,000 tons U_3O_8 this year up from 25,000 tons in 1978. By 1985, production may more than double to over 80,000 tons U_3O_8, a compounded annual growth rate of about 16 percent. By 1990, most of the major deposits now known will be in production at an annual rate exceeding 90,000 tons U_3O_8.

INTERNATIONAL URANIUM RESOURCE EVALUATION PROJECT (IUREP)

Since 1976, the United States has participated in an international effort to look at the geology of the nations of the world to identify areas favorable for uranium resources. Individual studies were made of 185 nations with particular attention to countries where the relative promise of finding uranium appears to exceed the relative amount of exploration effort done to date.

A preliminary report on the initial phase of IUREP was issued in 1978, and a complete report on the initial phase is expected to be published during 1980. The 1980 report should be of interest to companies engaged in exploration abroad because it provides a global view of geologic elements that are relevant to finding uranium.

The 1978 preliminary report conveyed a general impression of the order of magnitude of speculative resources up to $50 per pound U_3O_8 cost—thought to exist in the world. Estimates were made of the ranges of tonnages of uranium expected to be discovered within each continent (see table 3). As might be expected, the range of values is quite broad reflecting the speculative nature of the exercise and the uncertainties involved. There is no assurance, of course, that these resources will be discovered or, if discovered, produced. However,

TABLE 2. *Foreign production capability (thousand tons U_3O_8)*

Year	Australia	Canada	France	Gabon	Namibia	Niger	South Africa	Other	Totals
1979	0.8	9.0	3.8	1.3	4.8	4.3	6.8	1.5	32.3
1980	0.8	9.4	4.5	1.3	5.3	5.2	8.5	2.7	37.7
1981	3.0	11.7	4.7	1.3	5.7	5.2	9.5	3.5	44.6
1982	4.9	12.9	5.0	2.0	5.9	5.2	11.2	5.7	52.8
1983	6.5	14.3	5.2	2.0	6.5	5.2	12.9	6.8	59.4
1984	8.5	17.6	5.2	2.0	6.5	5.9	13.5	7.1	66.3
1985	15.6	18.7	5.2	2.0	6.5	7.8	13.8	7.8	77.4
1986	17.7	18.9	5.9	2.0	6.5	10.4	13.9	7.8	83.1
1987	19.8	18.9	5.9	2.0	6.5	10.4	13.9	7.9	85.3
1988	21.8	19.1	5.9	2.0	6.5	10.4	13.8	8.0	87.5
1989	23.9	20.0	5.9	2.0	6.5	10.4	13.8	8.1	90.6
1990	26.0	20.2	5.9	2.0	6.5	10.4	13.5	8.2	92.7

SOURCE: Modified from "Uranium Resources, Production and Demand," OECD Nuclear Energy Agency and the International Atomic Energy Agency, December 1977.

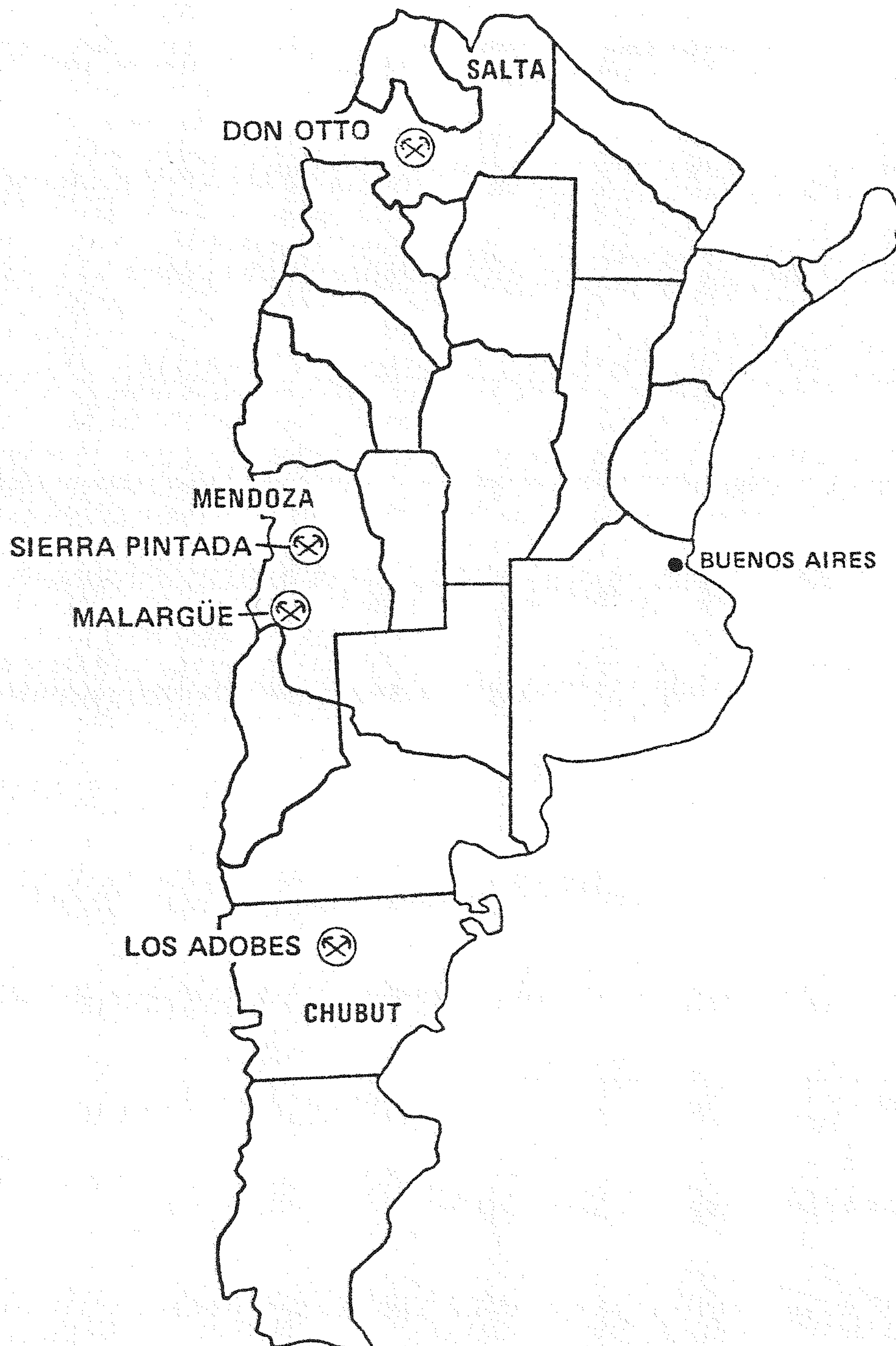


FIGURE 9. *Uranium deposits, Argentina*

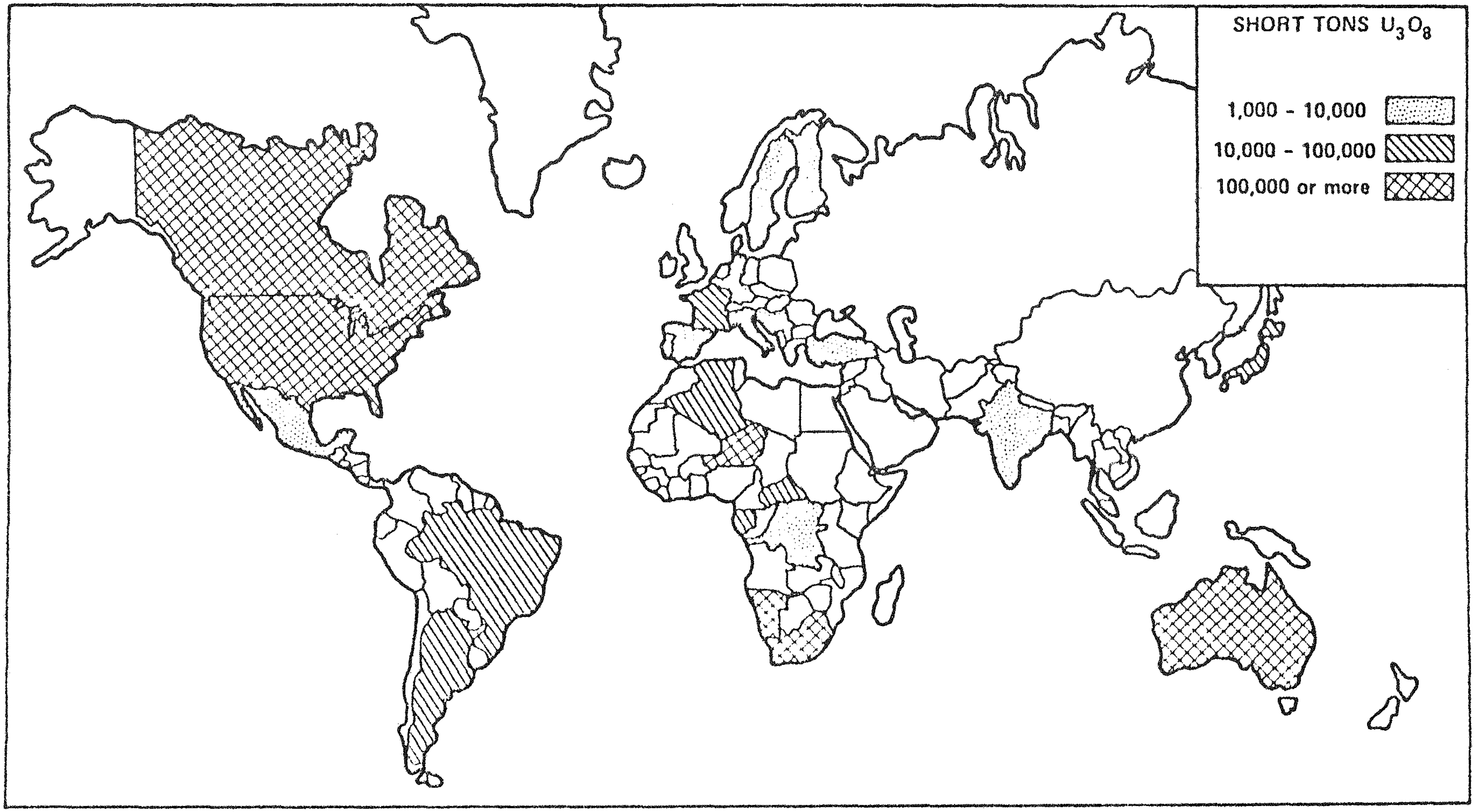


FIGURE 10. *Reasonably assured reserves of the world at up to $30 per pound U_3O_8*

(Peoples Republic of China, USSR, and associated states of eastern Europe are excluded).

FIGURE 11. *Estimated additional resources of the world at up $30 per pound U_3O_8*

(Peoples Republic of China, USSR, and associated states of eastern Europe are excluded.)

TABLE 3. *IUREP resource estimates by continent**
$50/lb U_3O_8

Continent	No. of Countries	Speculative Resources Million Tons U_3O_8
North America	3	2.7 - 4.7
Africa	51	1.6 - 5.2
Australia	18	2.6 - 3.9
Europe	22	0.4 - 1.7
Asia	41	0.3 - 1.3
South America	41	0.9 - 2.5
Total	176	8.5 - 19.3

* Excludes Eastern Europe, USSR and China.

the figures do provide a broad-brush estimate of the world's uranium.

CONCLUSIONS

The past 10 years have witnessed a remarkable increase in the pace of uranium exploration abroad, primarily in Australia, Brazil, Canada, France, and South Africa. This growth has been stimulated by discoveries of important deposits, particularly in Saskatchewan and the Alligator Rivers district of the Northern Territory that have added to the world's stores of uranium ore.

The past year has seen a slowdown in the growth of the exploration effort with 1978 expenditures at about the same level as 1977. However, significant discoveries continue to be made. In Argentina, Brazil, and Mexico, successful exploration has led to a significant expansion of resources during 1979.

The production capacity of nations outside the United States is predicted to grow markedly through 1985 at a compounded annual rate of about 16 percent as orebodies found during the 1970s are developed. An important contribution will also be made by expanded byproduct uranium recovery from South African gold operations.

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INTERNATIONAL NUCLEAR FUEL CYCLE EVALUATION NEARING CONCLUSION

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October 1979

At the Washington Conference in October of 1977, 40 nations established the International Nuclear Fuel Cycle Evaluation (INFCE). Since then, 16 more nations have joined, for a total of 56 participants. The purpose of INFCE is to consider how nuclear energy might be made widely available to meet world energy needs, and at the same time, how the risk of nuclear weapons proliferation might be minimized. The Conference divided the subject of the nuclear fuel cycle into eight parts and formed a working group to be responsible for each part. It also formed a Technical Coordinating Committee (TCC) to coordinate topics which involve more than one working group. The working groups have done a prodigious amount of work and are on schedule. They submitted draft reports, each with a summary, to the TCC in June. The TCC reviewed these at its meeting in July. Since then, all working groups have revised their reports in response to comments and are resubmitting them to the TCC for review at a mid-November meeting. The TCC will then transmit the reports for final acceptance at the February 1980 Plenary Session, after which the reports will be made public. The TCC is also in the process of writing a summary and overview to accompany the eight working-group reports. This document will be widely read by decision-makers around the world.

I propose to speak briefly about some of the key issues which INFCE has been considering. I am not in a position to say how INFCE will decide on these issues. So, bear in mind that I am not giving you INFCE conclusions but my own view of the significance of some key issues.

The nuclear fuel cycle can offer the possibility, through abuse, of providing material for making nuclear weapons. If carried out by a government, such action is defined as diversion. Diversion is not likely to be the most direct path to weapons material, but it could be done in secret, before the international community is aware of what is going on, and that would increase the danger. Proliferation-risk assessment involves three main considerations: the resources of trained manpower and facilities required to produce weapons usable material, the time required, and the difficulty of detection of the activity by the international community. In this paper, a few basic points will be covered.

In considering the proliferation risk of the nuclear fuel cycle, we can focus on three elements: enrichment, irradiated fuel, and in conjunction with the latter, reprocessing. Consider first enrichment. It is required to provide fuel material for many reactor types, notable exceptions being heavy-water reactors, graphite reactors, and some breeder reactors. If the material is highly enriched uranium (HEU), or about 90 percent ^{235}U, then the enrichment facility, the stocks of product material, or fresh fuel could be a proliferation risk. If the material is low-enriched uranium (LEU), it is not in itself a proliferation risk.

General statements are not so easy to make about the enrichment facility itself. If it is an operating facility today, it represents a base line, against which the risk of future additions could be measured. Future additions, particularly if they took place at many locations, would constitute an increase in risk. Improved safeguards, including material balances, containment, and surveillance, could compensate and reduce the risk of diversion. From a risk point of view, the best outcome for the next 15 years would be that new additions would not be necessary. The technology, obviously, is sensitive and should be closely held so as to minimize the possibility of clandestine plants being built.

Consider irradiated or spent fuel, which contains plutonium, or ^{233}U in the case of thorium, the amounts and isotopic content depending on the type of fuel, the reactor, and the irradiation history.

Irradiated fuel constitutes a low risk because of the radiation barrier which is effective for a long time—at least a hundred years in the case of light-water reactor (LWR) fuel. This is true, of course, provided that a would-be proliferator does not have a reprocessing facility at his disposal. Even though the risk of spent fuel is low, it does have to be safeguarded until it is reprocessed or is rendered unavailable by permanent disposal. Spent-fuel safeguarding will be an important activity because of the large quantities of spent fuel, i.e. 100,000 tons or more by the year 2000 in the World Outside Communist Areas (WOCA).

Consider reprocessing. Reprocessing is necessary for breeder reactors, for recycle in LWRs, and for other converter reactors. The risk in reprocessing derives from separated plutonium which is available in the process, in inventory or in mixed oxide used in the fabrication of fresh fuel, or in the fresh, unirradiated fuel itself. Reprocessing facilities in operation, whether commercial or for R&D, will increase proliferation risk. The risk will depend on the number of reprocessing facilities, plutonium storage points, recycle fuel fabrication plants, and also the amount of plutonium in circulation. To some extent, coprocessing or spiking of new fuel could decrease the risk. Improved safeguards would be a more important factor in risk reduction as would planning to maintain production capacity and needs in balance, so as to minimize inventories.

These three elements, then, are the important fuel-cycle elements relating to proliferation questions. How to quantify the risks is not known. Each situation has to be considered case-by-case and compared to an existing base line. To assess risks in the future, one should try to anticipate changes in technology and how these would affect risk. For example, a denatured fuel, consisting of ^{233}U in natural uranium, would be evaluated less favorably in the future if enrichment technology is assumed to be more available than it is today.

It is useful to look at various reactor-fuel cycles and compare them. Proliferation risk is not the only important factor. Other important ones include: energy availability, health, safety and environment, technical and economic factors, and institutional considerations. I might note that INFCE did not evaluate reactor health and safety or environmental questions in great detail although it probably would have done so if the study had started later.

So then, let us look at the light-water reactors (LWRs) on a once-through cycle, LWRs on recycle, and fast-breeder reactors (FBRs) in the terms of these assessment factors.

First, the LWR on a once-through cycle is shown in table 1. With regard to energy availability, the LWR has large uranium requirements, i.e. about 4,300 metric tons (MT) of natural uranium per 1 gigawatt (GWe) for 30 years of operation at 70-percent capacity factor and 0.2-percent enrichment plant tails assay. It has a low proliferation risk for reasons already discussed. It should be emphasized that the proliferation risk from enrichment has been low because enrichment has been widely available at reasonable prices, mostly from the United States. The proliferation-risk assessment would be affected by the widespread addition of new plants, and particularly so, if they are not needed from a supply point of view.

In the assessment of health, safety, and environment, waste disposal is both a very important technical question and is highly visible in the eye of the public. For the once-through cycle, spent fuel would be stored in pools for a decade or more before final geologic disposal. Pool storage does not appear to have technical problems although more data are needed on long-term storage. Experts are confident that geologic disposal will be technically feasible, but more R&D is needed. Uranium mill tailings are an important consideration because they dominate the fuel-cycle radiological impact on the environment. Although the impact is

TABLE 1. *LWR once-through cycle assessment*

Assessment Factors	Reference LWR
Energy availability	Uranium resources limited
Proliferation risk	New enrichment plants Spent-fuel storage
Health, safety, and environment	Mill tailings Waste disposal (spent fuel)
Technical–economic	Reference
Institutions	Supply assurances New enrichment-plant management Spent-fuel storage management Safeguards

small compared to background radiation, it continues for a long, long time unless the tailings are adequately covered.

In the technical-economic assessment, the LWR once-through can be considered a reference cycle because it is in wide commercial use today, is competitive with coal, and is cheaper than oil.

The LWR institutional considerations have two aspects: supply assurances and institutional frameworks for managing and safeguarding new enrichment facilities and spent-fuel storage facilities. Supply assurances for uranium and enrichment services are vital to consumer nations in order to minimize the possibility of power interruption. Supply assurances will be an important factor in minimizing proliferation risk because the perceived need for national enrichment plants for the sole purpose of energy independence will be reduced.

New institutional arrangements could play an important role in the management and safeguarding of new enrichment plants, when they are needed, and in the spent-fuel storage facilities. These institutions could take the form of multinational business ventures. The development of these institutions will have to address important questions, such as the incorporation of safeguards features into the design of new facilities, cooperation with international authorities, the transportation of material across national borders, and the restriction of sensitive technology and components to prevent them from becoming widely available.

The LWR recycle assessment is shown in table 2. Applying the same assessment factors, one can see that there are some differences. LWR recycle requirements are in principle about 35 percent less than the once-through cycle. A greater proliferation risk has to be attached to recycle because the availability of separated plutonium would increase if reprocessing and fabrication plants are deployed in the future.

The health, safety, and environmental assessment changes somewhat. Disposal involves reprocessing waste rather than spent-fuel elements, and the possibility of radiation exposure from reprocessing effluents has to be considered.

The economic issue with reference to the once-through cycle is whether or not reprocessing is advantageous. The benefit of reprocessing is determined by the value of uranium and enrichment service which reprocessing displaces. The question is—is there an incentive for recycle, given uranium prices which are expected in the near-term and the cost of reprocessing and fabrication? There appears to be little, if any, incentive for thermal recycle for the foreseeable future.

TABLE 2. *LWR recycle assessment*

Assessment Factors	LWR Recycle
Energy availability	Better uranium utilization
Proliferation risk	Plutonium available
Health, safety, and environment	Mill tailings Waste disposal (solidified waste) Reprocessing effluents
Technical–economic	Recycle economics Reprocessing investment
Institutions	Supply assurance New enrichment-plant management Reprocessing and fuel-fabrication management Plutonium-storage management Spent-fuel storage management Improved safeguards

The institutional assessment for LWR recycle includes the same considerations as the once-through system. However, if recycle were to proceed, there is need for development of new institutions for reducing the risks from reprocessing and fabrication operations and for plutonium storage. Safeguards improvement in all these regimes would be a major focus of development for the international community.

Finally, the fast-breeder reactor assessment is shown in table 3. Energy availability is much improved, potentially by a factor of 60 or more, compared to the once-through LWR. The proliferation risk is also increased, compared to the LWR recycle, because of large plutonium flows. In the health, safety, and environmental assessment, there are several differences. Mill tailings would be reduced in relation to the extent of breeder

TABLE 3. *Fast breeder reactor assessment*

Assessment Factors	Fast Breeder Reactor
Energy availability	Much, much better
Proliferation risk	Large plutonium flow
Health, safety, and environment	New technology criteria and standards Waste disposal Reprocessing effluents
Technical-economic	Breeder capital cost Break-even cost with LWR
Institutions	Reprocessing and fuel-fabrication management Plutonium-storage management Spent-fuel storage management Further improvements in safeguards

deployment because of the improved uranium utilization. On the other hand, the new technology requires the development of new safety criteria and standards. The problems of reprocessing effluents and waste disposal might differ somewhat in degree, but not in kind, from LWR recycle.

In the economic assessment of breeders, the most important question is the determination of the time when breeder-reactor power costs will reach a break-even point with the LWR. What it comes down to is a trade-off in higher capital cost and fuel-recycle cost against uranium-ore savings. The uncertainties in breeder capital cost and future uranium cost, as well as nuclear load growth, are such that at best, the time of breeder introduction on economic grounds can only be specified in a broad time span, sometime between 2000 and 2030. Countries view uranium supply from different perspectives; and so opinions vary considerably on the time of introduction.

Breeder reactors are not expected to play a significant role in developing countries for a long time. The development costs are high, and investment in other technologies would pay off sooner. The breeder does not provide energy independence in a short period of time. Also, small electric grids are not very compatible with the expected size of economic breeders.

The institutional problems related to breeder reactors are similar in kind to LWR recycle problems, but they will be more difficult to manage because the plutonium flows and inventories will be higher. Further safeguards improvements will be needed.

We can now compare the assessments of these three cycles. This comparison is shown in table 4, which gives the LWR once-through assessment as a reference, the changes relative to the LWR once-through for LWR recycle, and the changes for fast-breeder reactor. Going from left to right, from the existing LWR toward the breeder, energy availability is enhanced significantly. At the same time, proliferation risks increase significantly with recycle and, again, with the breeder. The burden of compensating for and reducing proliferation risk falls on institutional development and safeguards. It will take time and effort to solve the problems.

One can approach the economic assessment from a number of points of view, but, given the doubtful incentive for thermal recycle, it does not seem to be worth the proliferation risk. In the case of the breeder, there appears to be time, if deployment is based on economics, to undertake the institutional development, but the task should be undertaken without delay.

The health, safety, and environmental differences are more technical in nature. Probably the important conclusion is that solution of the waste disposal problem is essential to all fuel cycles.

The comparison clearly shows the benefits and the risks of the LWR recycle and the breeder reactor. It raises the key question—when will a transition have to be made for deployment of the breeder reactor? To answer the question of when to deploy, we need to consider two key points.

The first point is that U.S. nuclear power forecasts have shown large declines in the past few years, i.e. by a factor of five since 1974 for the total capacity in the year 2000. The causes are partly rising costs affecting all generation and partly specific nuclear problems including licensing delays, capital-cost increase, and controversy over waste disposal and safety. It is valid to question whether or not similar problems will slow down nuclear programs in other countries. Table 5 shows the Energy Information Agency (EIA)/DOE forecast of May 1979 for the World Outside Communist Areas (WOCA). Below it are the data from the August 20

TABLE 4. *Assessment comparison*

	LWR Once-Through	LWR Recycle	Fast Breeder Reactor
Energy availability	Uranium limited	Better	Much better
Proliferation risk	New enrichment plants Spent-fuel storage	Plutonium available	Large plutonium flow
Health, safety, and environment	Mill tailings Waste disposal	Solidified waste Reprocessing effluents	New technology criteria and standards
Technical-economic	Reference	Recycle economics Reprocessing investment	Breeder capital cost Break-even cost with LWR
Institutions	Supply assurance Enrichment-plant management Spent-fuel storage management Safeguards	Reprocessing management Plutonium-storage management Improved safeguards	Reprocessing management Plutonium-storage management Further improvements in safeguards

TABLE 5. *WOCA nuclear power forecast*

	1985	1990	1995	2000
EIA/DOE May 1979	216–247	305–376	418–521	–
INFCE 1978	245–274	373–462	550–770	850–1200

Nuclear Fuels Letter, purported to be the INFCE 1978 forecast. The more recent EIA forecast is significantly lower, i.e. by about 30 percent in 1995. If the lower forecast turns out to be a closer approximation to actuality, then the existing systems, such as the LWR, can be deployed for a longer time before approaching resource limits. The delay of nuclear power growth, in general, means the delay of advanced and breeder reactors.

Uranium resources and availability is the second point. That is the topic of this meeting, and I know that you can shed far more light on it than I. I will say that the possibility has been discussed in the past several years of large speculative resources. Such a development would defer the proliferation risks associated with sensitive fuel-cycle facilities and allow time to put improved safeguards in place for breeder reactors when they are needed. So, the topic of your meeting and the outcome of discussion have great importance and many ramifications to the deployment of nuclear energy now and over the next 20 years.

The outcome of INFCE will be decided collectively and made known early next year. I believe that it will establish technical findings on a common basis across the entire nuclear fuel cycle. This should serve to clarify the issues and the options for the purpose of policy making within governments, and it should serve the development of future international accords on nuclear nonproliferation, in order that the use of nuclear energy may evolve with a minimum of proliferation risks. I expect to see growing activity in these areas, which will follow the formal completion of INFCE and the issuing of the INFCE reports in February of next year.

URANIUM RESERVES

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October 1979

INTRODUCTION

A major consideration in national decisions regarding the future role of nuclear power is the uranium-supply base that will be available. To provide timely information essential to studies on nuclear fuel supply, the Grand Junction Office (GJO) of the U.S. Department of Energy (DOE) maintains a comprehensive program of uranium resource and supply assessment. The assessment program includes the continuing analysis and estimation of domestic uranium reserves and potential resources, and the monitoring and analysis of industry's exploration, development, and production activities. The success of the uranium resource and supply evaluation program depends on the availability of data generated by both the uranium industry and the National Uranium Resource Evaluation (NURE) program of DOE.

Uranium reserves are the estimated quantities of uranium which occur in known deposits of such grade, quantity, configuration, and depth that they can be recovered at, or less than, a specified cost using proven mining and processing technologies. Estimates of tonnage and grade are based on specific sample data and measurements of the deposit and on knowledge of ore-body habit. Sample data, primarily gamma-ray logs of drill holes, are voluntarily made available to GJO by uranium companies. Estimates of the amount of uranium that could be exploited at a maximum forward cost of $15, $30, and $50 per pound U_3O_8 are calculated by using consistent engineering procedures and pertinent economic criteria. Forward costs are those costs to be incurred for exploitation of each deposit at the time the estimate is made.

This paper includes reviews of: (1) the distribution of January 1, 1979, reserves, (2) the concepts, types of basic data, and methods used by GJO for uranium reserve estimation, (3) confidence levels for reserve estimates, (4) other reserve estimation methods and comparisons of results, and (5) the outlook for 1980.

DISTRIBUTION OF JANUARY 1, 1979, RESERVES

The major portion of domestic uranium reserves continues to be assigned to Mesozoic and Tertiary sandstones in a few areas, primarily the Grants mineral belt, New Mexico, the Tertiary basins, Wyoming, the Gulf Coastal Plain, Texas, and the Paradox Basin, Colorado and Utah. The locations of the principal areas and the magnitude of these reserves are illustrated in figure 1.

Table 1 shows estimates of January 1, 1979, domestic reserves for the $15, $30, and $50 cost categories by tons of ore, average grade, and pounds U_3O_8.

TABLE 1. *U.S. uranium reserves* January 1, 1979*

$/lb U_3O_8 Cost category	Tons ore (millions)	Avg. grade (% U_3O_8)	Tons U_3O_8 (X 1000)
$15	166	0.18	290
$15—30 Increment	548	0.07	400
$30	714	0.10	690
$30—50 Increment	586	0.04	230
$50	1,300	0.07	920

*Does not include byproduct uranium.

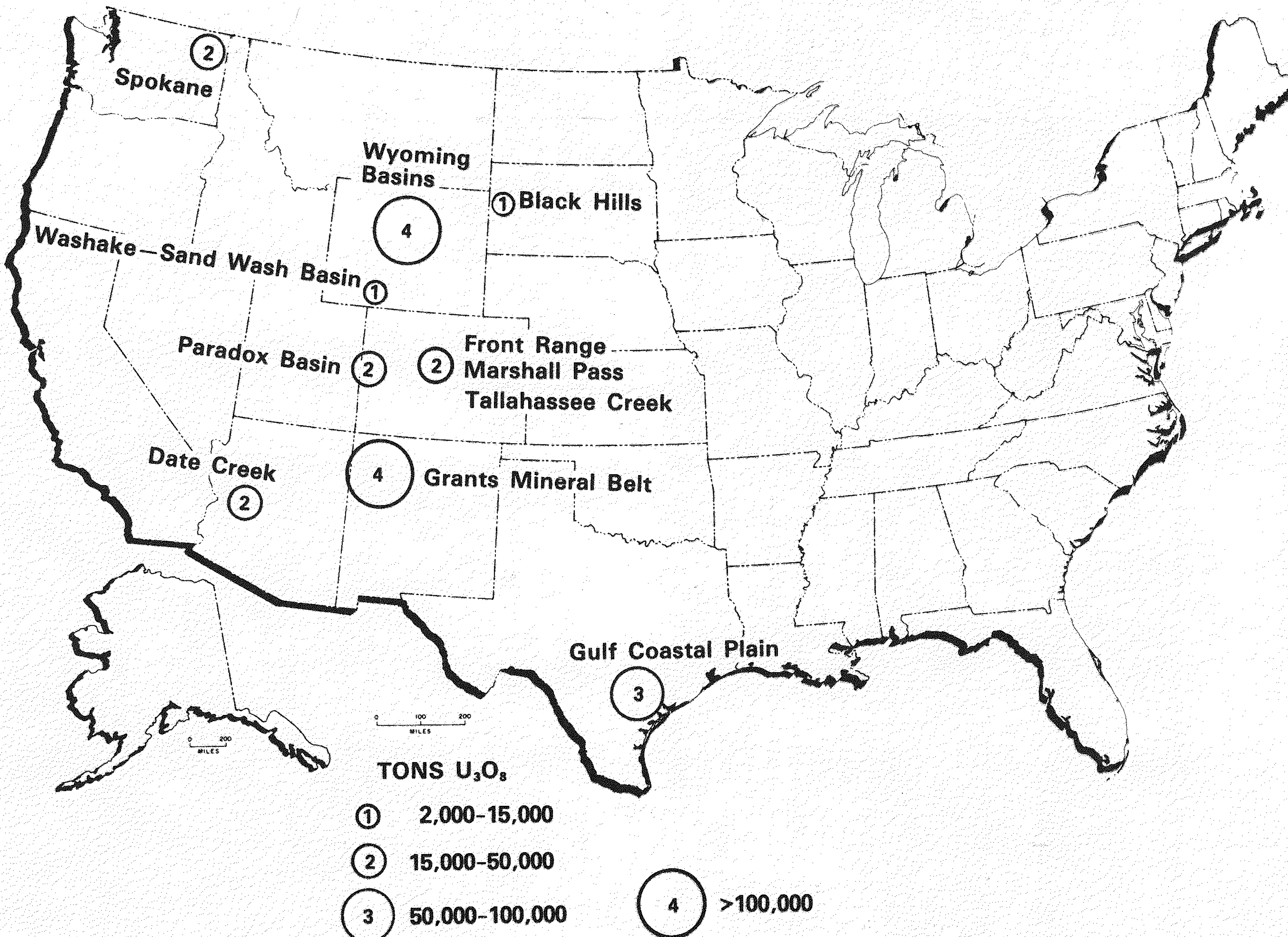


FIGURE 1. *Distribution of 1/1/79 $50 reserves*

TABLE 2. *Changes in reserves by cost categories during 1978*

Quantities in Thousands of Tons

	$15 Reserves			$30 Reserves			$50 Reserves		
	Ore	% U_3O_8	U_3O_8	Ore	% U_3O_8	U_3O_8	Ore	% U_3O_8	U_3O_8
1015 Properties Total $15 Reserves	166,000	0.18	290	406,000	0.11	436	697,000	0.08	551
518 Properties are added @ $30/lb				308,000	0.08	254	577,000	0.06	351
1533 Properties Total $30 Reserves				714,000	0.10	690			
279 Properties are added @ $50/lb							26,000	0.07	18
1812 Properties Total $50 Reserves							1,300,000	0.07	920

Properties containing 150 or more tons U_3O_8 in each cost category 1/1/79

	$15	$30	$50
Number of properties	131	306	346
Tons U_3O_8 (thousands)	280	672	899
Percentage of total tons U_3O_8	96	97	98
Percentage of properties	13	20	19

Although most of the $50 reserves continue to be associated with lower cost reserves (see table 2), the number of properties with $50 reserves not associated with lower cost reserves increased from 15 properties in 1977 to 279 properties in 1978. Approximately 97 percent of the $30 reserves are on 306 properties (20 percent) and 98 percent of the $50 reserves are on 346 properties (19 percent).

Table 3 shows the factors comprising the changes in $15, $30, and $50 reserves during 1978. Reserve additions, representing evaluations of new properties and reevaluations of old properties based on additional drill-hole data and current-cost data, amounted to 44,000 tons U_3O_8 in the $30 cost category. Reserve additions to the $15 category were obtained from reevaluations of old properties based on new drilling data; there were no additions to the $15 category from new properties. The 73,000-ton addition to the $50 reserves during 1978 was similar to that in 1977; however, a larger quantity was subtracted from the $50 category during 1978 due to reevaluations using higher mining costs. Reevaluation also resulted in large reductions amounting to 77,000 tons U_3O_8 in the $15 reserves and 23,000 tons in the $30 reserves. These reductions do not indicate decreases in the estimated amount of uranium present in the ground; they do indicate that due to rising production costs, less uranium is available at the respective forward costs. After further reductions because of production, the net changes from a year earlier were a reduction of 80,000 tons in the $15 reserves, no change in the $30 reserves, and an increase of 30,000 tons in the $50 reserves.

Table 4 shows 44 percent of the $50 reserves to be on producing properties, and 56 percent to be on nonproducing properties. Of the 514,200 tons U_3O_8 of $50 reserves on nonproducing properties, 383,100 tons, or about 42 percent, probably will be mined by underground operations that will require substantial capital expenditures for development. The rapidly rising costs of underground development could soon result in a significant reduction of the underground $50 reserves upon reevaluation.

URANIUM INVENTORIES

Uranium inventories compiled by GJO from company-drilling data include all material equal to or exceeding minimum mining thicknesses, and equal to or greater than 0.01 percent U_3O_8, with no consideration of economic availability. The post-production inventory discussed in this paper excludes all production prior to the estimates. Table 5 shows the January 1, 1979, U. S. postproduction uranium inventory. Figure 2 is a graphic representation of U.S. postproduction uranium inventory for each of the past 3 years that illustrates upward growth of the inventory since January 1, 1977. Additions to the postproduction inventory during 1977 and 1978 amounted to 103,000 tons U_3O_8 and 94,000 tons U_3O_8, respectively. About two-thirds of the postproduction inventory comprises January 1, 1979, reserves, and the remaining one-third would be available only at costs exceeding $50 per pound U_3O_8.

CONFIDENCE LEVELS

To indicate reliability of the January 1, 1979, reserves, estimates were made in terms of confidence levels. The 0.95 and 0.05 confidence limits for each key variable used in reserve estimation including grade, thickness, area of deposit, disequilibrium, quality of data, tonnage factor, cost, and mining recovery were then assigned for each property. The interdependencies between key variables, such as the relationship of the economic cutoff grade to mining/milling costs and the average grade to cutoff grade, were considered in the assignment of confidence limits to key variables.

TABLE 3. *Changes in reserves during 1978 (tons U_3O_8)*

STATUS	$15	$30	$50
January 1, 1978 reserves	370,000	690,000	890,000
New reserves	0	10,000	20,000
Reevaluation—additions	16,000	34,000	53,000
Reevaluation—subtractions	(77,000)	(23,000)	(21,000)
Depletion—production	(19,000)	(21,000)	(22,000)
January 1, 1979 reserves	290,000	690,000	920,000

TABLE 4. *Distribution of 1/1/79 $50 reserves by mining method in producing and nonproducing properties*

		Tons Ore	% U_3O_8	Tons U_3O_8	No. Properties	% Total Tons U_3O_8
Producing properties	Open pit	305,500,000	0.06	174,500	331	19
	Underground	299,500,000	0.07	219,400	943	24
	Others	26,100,000	0.05	11,900	21	1
	Total	631,100,000	0.06	405,800	1,295	44
Nonproducing properties	Open pit	203,800,000	0.06	112,400	246	12
	Underground	420,300,000	0.09	383,100	210	42
	Others	44,400,000	0.04	18,700	61	2
	Total	668,500,000	0.08	514,200	517	56

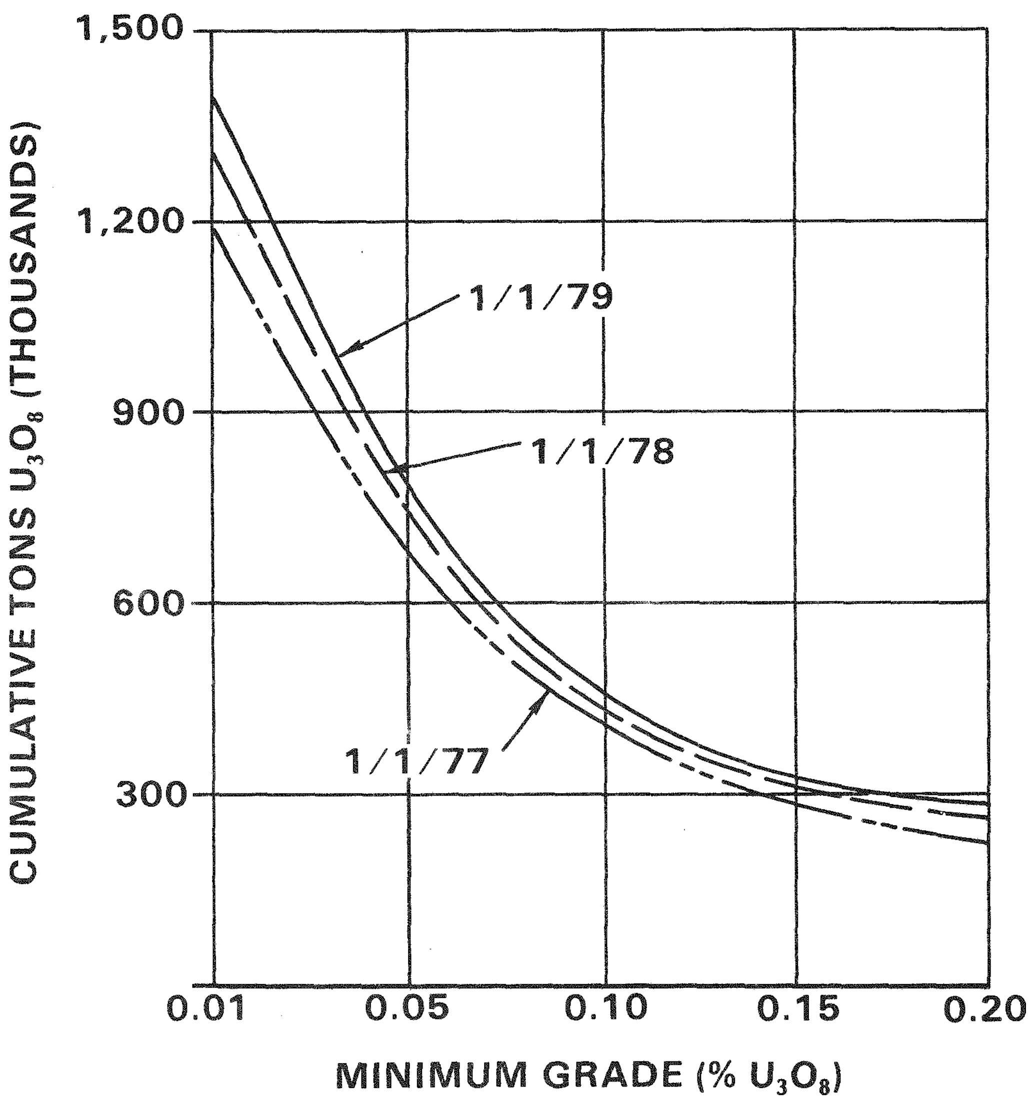


FIGURE 2. *U.S. postproduction uranium inventory 1/1/77, 1/1/78, and 1/1/79*

TABLE 5. *United States postproduction uranium inventory, 1/1/79*

Minimum Grade (% U_3O_8)	Cumulative Tons of Ore (Millions)	Avg. Grade (% U_3O_8) of Cumulative Tons	Cumulative Tons U_3O_8 (Thousands)
0.01	3,210	0.04	1,381
0.02	2,068	0.06	1,214
0.03	1,379	0.08	1,044
0.04	973	0.09	915
0.05	725	0.11	806
0.06	552	0.13	714
0.07	428	0.15	635
0.08	335	0.17	566
0.09	268	0.19	510
0.10	217	0.21	456
0.11	187	0.23	429
0.12	163	0.25	403
0.13	147	0.26	379
0.14	131	0.28	360
0.15	120	0.29	345
0.16	107	0.31	328
0.17	98	0.32	312
0.18	89	0.33	296
0.19	80	0.35	281
0.20	74	0.36	267

Note: These figures do not represent reserves, since the economics of exploitation are not taken into account.

The key variables for each property were then convoluted (combined) into a probability function, assuming variable independence. Properties were stratified (grouped) into subsets based on geologic similarity and geographic proximity, and the properties in each subset were judged to have a correlation coefficient of one. The probability functions of the key variables for each property in a subset were then convoluted by computer into a probability function for the subset.

Probability functions for subsets were then convoluted into an aggregate probability distribution for the domestic reserves by assuming a correlation coefficient between subsets to be equal to 0, because they are judged to be mutually or statistically independent. The resulting estimates of reliability were in ranges of ± 15 percent for the $30 reserves and ± 17 percent for the $50 reserves at the 90-percent confidence level (the interval between the 5- and the 95-percent confidence limits). Figures 3 and 4 show cumulative probability distribution curves for the January 1, 1979, $30 and $50 reserves.

CHANGES IN RESERVES—1967 THROUGH 1978

Figure 5 shows the annual changes in year-end reserves for the years 1967 through 1978 in the highest reserve-cost category calculated by GJO for each of those years. In 1966, the highest cost category of estimated reserves was $10 per pound U_3O_8. During the next 6 years, $15 reserves were estimated. In 1973, a $30 category was added, and a $50 category was added in 1976. Also in 1976, estimation of the uranium inventory, which includes all material containing 0.01 percent or more U_3O_8, was begun. As stated earlier, part of the uranium inventory would be available only at costs exceeding $50 per pound U_3O_8.

Increased production costs and concentrate prices prompted the adoption of the higher cost categories, thus resulting in a more comprehensive estimate of the Nation's uranium resource base. During the past 12 years, with the continued industry exploration and with the introduction of these higher reserve-cost categories, the reserves increased from 200,000 tons U_3O_8 to 920,00 tons U_3O_8. The mineral inventory has attained a level of about 1,400,000 tons U_3O_8 increasing at an annual rate of nearly 100,000 tons U_3O_8 in the 2 years since its inception.

RESERVE ESTIMATION METHODS

General Outline Method (For Open-Pit Reserves)

Reserves of orebodies minable by open-pit methods, are estimated by the general outline method. The costs of mining such deposits are a function of depth, size, configuration, thickness, and grade of ore. A separate pit evaluation is performed for each reserve-cost category.

A computer program to analyze reserves minable by open-pit methods has been designed as a series of subroutines, each carrying out a specific phase of the calculation. The program considers: (1) the thickness and grade of material in each drill hole that equals or exceeds an economic cutoff needed to meet mining and milling operating costs, (2) whether or not the value of this material will also carry the cost of excavating overlying waste, and (3) the economics of a total open-pit operation based on the cost of overburden removal, mining, milling, and forward capital costs.

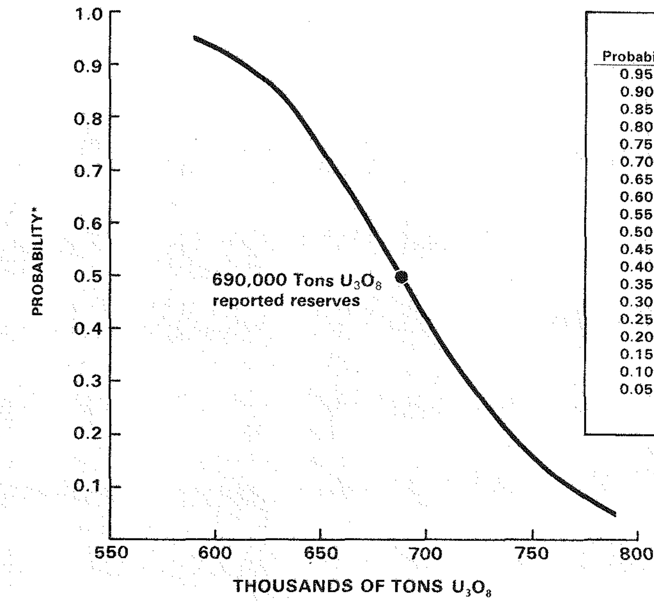
The first subroutine of the program analyzes the sample data on a hole-by-hole basis (see figure 6). A map is then plotted from this drill-hole information, which is used to outline a pit bottom by grouping the data into minable zones based on grade cutoffs and minimum mining thickness. The perimeter and area of this pit bottom are measured by an engineer, and these pit dimensions, together with the data from the hole-by-hole analysis and economic parameters, are the input for a computer routine that calculates the economic tons of ore, average grade of ore, average thickness of ore, average depth of overburden, stripping volumes (including backslope), and total forward capital costs for the open-pit operation (see figure 7).

Statistical Method (For Underground Reserves)

Reserves of properties expected to be mined by underground methods are calculated by a somewhat new and different computer-programmed statistical method referred to as ORSAC. This method is based on the log-normality of the assay data.

Basic sample data, usually derived by interpretation of gamma-ray logs, are plotted on a drill-hole map, and the deposit is outlined. The deposit is divided into minable units. The U_3O_8 values are then combined into designated minimum thicknesses, and the grade-tonnage distribution is determined for each unit by calculating: (1) the fractional parts of the total tons that are above cutoffs ranging from 0.01 to 0.60 percent U_3O_8 in increments of 0.01 percent U_3O_8, and (2) the average grade of each fractional tonnage. The tonnage and grade of reserve in each cost category, corresponding to the predetermined grade cutoff, is selected from this grade tonnage distribution. Figure 8 shows the computer printout of an analysis of a grade-tonnage distribution, in 0.01 percent grade-cutoff increments ranging from 0.01 percent to 0.60 percent U_3O_8. Figure 9 shows graphically the same grade-tonnage distribution by average grade and quantity of reserves in percentage of tons of ore and pounds U_3O_8.

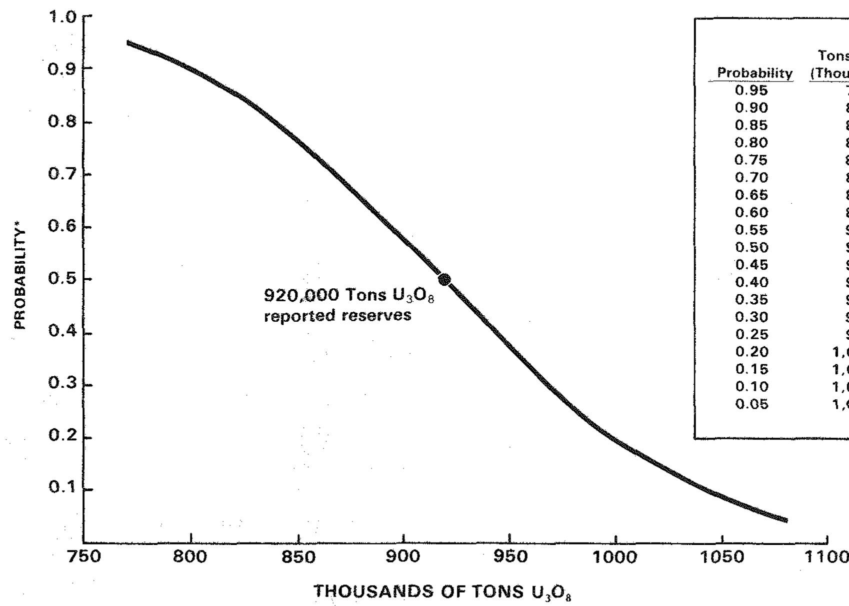
Table 6 shows comparisons of reserves estimated by statistical method versus production.



Probability	Tons U_3O_8 (Thousands)
0.95	590
0.90	610
0.85	630
0.80	640
0.75	650
0.70	655
0.65	665
0.60	670
0.55	680
0.50	690
0.45	695
0.40	700
0.35	710
0.30	720
0.25	730
0.20	740
0.15	750
0.10	770
0.05	790

*Probability of reserves exceeding given tonnage of U_3O_8

FIGURE 3. *Cumulative probability* distribution curve for 1/1/79 $30 reserves*



Probability	Tons U_3O_8 (Thousands)
0.95	770
0.90	800
0.85	820
0.80	840
0.75	850
0.70	870
0.65	880
0.60	890
0.55	900
0.50	920
0.45	930
0.40	940
0.35	950
0.30	960
0.25	980
0.20	1,000
0.15	1,020
0.10	1,040
0.05	1,080

*Probability of reserves exceeding given tonnage of U_3O_8

FIGURE 4. *Cumulative probability* distribution curve for 1/1/79 $50 reserves*

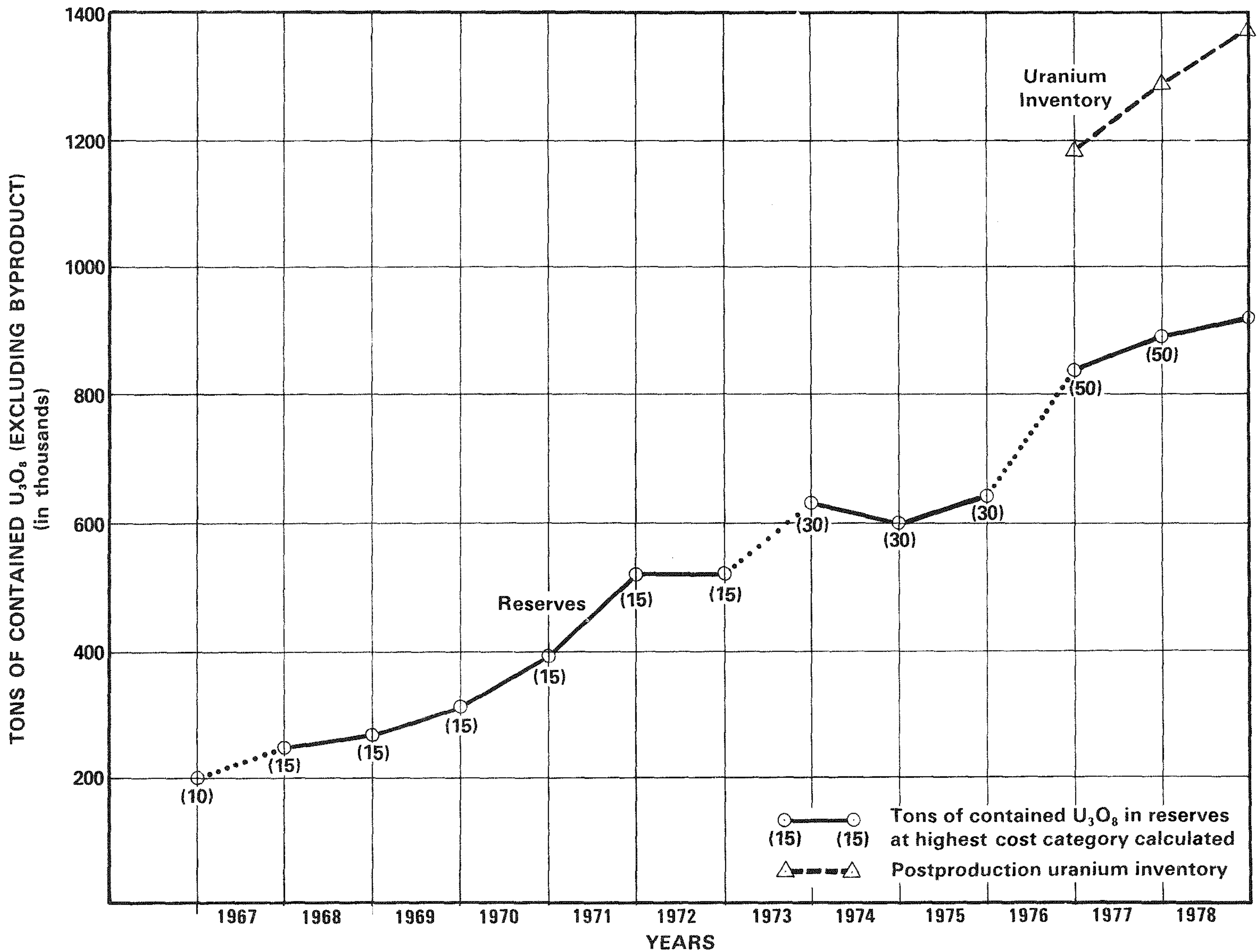


FIGURE 5. *Changes in estimates of reserves and uranium inventory (1967–1978)*

(THE USERDA DOES NOT WARRENT THE INFORMATION CONTAINED HEREON TO BE ACCURATE IN ALL RESPECTS AND MAKES NO RECOMMENDATIONS THERETO)

ORE ZONE EVALUATION FOR - DISPLAY 11/09/76 PAGE 2

OPEN PIT EVALUATION	BLK NO.	HOLE COUNT	N COORD.	E COORD.	ELEV.	PIT ELEV.	TOTDPTH	HOLE ID
		45	953500	998300	7732	0	202.0	A 39

WILL ORE CARRY OVERBURDEN	YES	YES	YES	YES	YES
GRADE CUTOFF, PERC U308.	.03	.05	.10	.15	.195
MAX COST / LB U308	$50.00	$30.00	$15.00	$10.00	$ 8.00
DEPTH TO FIRST ORE ZONE	48.5	86.0	90.5	91.0	91.0
ELEV. AT TOP OF IST ZONE	7683.5	7646.0	7641.5	7641.0	7641.0
*** ORE ZONE, THICKNESS	2.00	8.00	3.00	2.50	2.50
GRADE OF ORE, PCT U308.	.04	.10	.20	.22	.22
CUM. UNIT MARGIN ($)	$ -0.12	$ 13.13	$ 2.55	$ -0.64	$ -2.00
*PROTORE, THICKNESS	0	0	0	0	0
GRADE OF PROTORE					
DEPTH TO TOP OF ORE	86.00	111.00	140.00	140.50	141.00
*** ORE ZONE, THICKNESS	9.00	2.00	3.00	2.50	2.00
GRADE OF ORE, PCT U308.	.09	.05	.33	.38	.44
CUM. UNIT MARGIN ($)	$ 31.60	$ 12.93	$ 13.05	$ 4.49	$ 1.22
*PROTORE, THICKNESS	0	0	0	0	0
GRADE OF PROTORE			0	0	0
DEPTH TO TOP OF ORE	100.00	139.00	0	0	0
*** ORE ZONE, THICKNESS	7.00	5.50	0	0	0
GRADE OF ORE, PCT U308.	.03	.20	0	0	0
CUM. UNIT MARGIN ($)	$ 31.40	$ 40.35	$ 0	$ 0	$ 0
*PROTORE, THICKNESS	0	0	0	0	0
GRADE OF PROTORE		0	0	0	0
DEPTH TO TOP OF ORE	110.50	0	0	0	0
*** ORE ZONE, THICKNESS	4.50	0	0	0	0
GRADE OF ORE, PCT U308.	.04	0	0	0	0
CUM. UNIT MARGIN ($)	$ 34.09	$ 0	$ 0	$ 0	$ 0
*PROTORE, THICKNESS	0	0	0	0	0
GRADE OF PROTORE		0	0	0	0
DEPTH TO TOP OF ORE	138.50	0	0	0	0
*** ORE ZONE, THICKNESS	7.00	0	0	0	0
GRADE OF ORE, PCT U308.	.16	0	0	0	0
CUM. UNIT MARGIN ($)	$ 84.75	$ 0	$ 0	$ 0	$ 0
TOTAL ORE THICKNESS	29.50	15.50	6.00	5.00	4.50
TOTAL ORE AVG. GRADE.	.08	.13	.26	.30	.32
TOTAL PIT STRIP. WASTE.	116.00	129.00	137.00	138.00	138.50
TOTAL PIT MNG. WASTE.	0	0	0	0	0
TOT. PROTORE THICK.	0	0	0	0	0
TOT. PROTORE AVG. GRD.	0	0	0	0	0

FIGURE 6. *Example of computer output for single hole in hole-by-hole analysis*

DISPLAY

TOTAL NUMBER OF BLOCKS USED IN THIS SUMMARY = 1

THIS TEST CONSIDERS U_3O_8 AT A MAXIMUM FORWARD COST OF $ 30.00 PER POUND.

AN ANGLE OF 63 DEGREES WAS USED TO CALCULATE THE BACKSLOPE OF THE PIT.

TONNAGE FACTOR USED--- 16.00 CUBIC FEET PER TON.

MINE EXTRACTION USED IN THIS TEST 100 PERCENT

MINING DILUTION USED IN THIS TEST 10 PERCENT

COSTS USED PER TON-		
	MINING	$ 4.00
	MILLING	$ 10.00
	INDIRECT	$ 2.00
	HAULAGE	$ 5.00
	ROYALTY	$ 3.50
	ADVALOREM	$ .35

MINING GRADE OF ORE	.09	PIT AREA IN SQ. FEET	128,200
MINABLE POUNDS	185,000	COST PER TON	$24.85
TONS OF ORE	102,600	TOTAL COST	$2,550,000
MILL RECOVERY	.90	RECOVERABLE POUNDS U_3O_8	167,000

RATIO OF YARDS OVERBURDEN TO POUNDS U_3O_8	= 2.51
RATIO OF TONS OVERBURDEN TO POUNDS U_3O_8	= 4.2
POUNDS U_3O_8 PER SQUARE FOOT OF AREA	= 1.3
POUNDS U_3O_8 DISCOVERED PER HOLE DRILLED	= 5,964
POUNDS U_3O_8 PER FOOT DRILLED	= 77.1

COST TO STRIP, MINE & MILL	$ 2,864,000	PIT PERIMETER IN FEET	1,700
MAXIMUM FORWARD COST MINUS REC. COST	$ 12.85	STRIPPING COST PER YARD	$ .75
COST PER RECOVERABLE POUND	$ 17.15	TOTAL YARDS IN BACKSLOPE	101,000
		YARDS DIRECT OVERBURDEN	307,000
MAXIMUM ALLOWABLE FORWARD COSTS	$ 5,010,000		
		YARDS WASTE IN PIT BOTTOM	5,000
		APPROXIMATION FOR RAMP	6,000
		TOTAL VOLUME OF OVERBURDEN	418,000
PERCENT	75	TOTAL COST OF STRIPPING	$314,000

PERCENT IS THE MAXIMUM FORWARD COST MINUS RECOVERABLE COST - DIVIDED BY - COST PER RECOVERABLE POUND

THE ORE AREA WAS REDUCED IN THIS RUN FROM 128,000 SQUARE FEET TO 119,000 SQUARE FEET DUE TO 2 BARREN HOLES IN THE PIT B

FIGURE 7. *Example of open-pit evaluation—open-pit economic test (not including cost of installation)*

STATISTICAL ANALYSIS BASED ON COMPOSITED URANIUM ASSAY VALUES

TONNAGE CALCULATIONS -

TOTAL TONS = TOTAL AREA * AV.THICK * NUMBER MIN. HOLES / TOTAL NUMBER HOLES/ TON. FACTOR

TOTAL TONS - 673163 AT AN AVERAGE GRADE OF .133 - TOTAL POUNDS U3O8 - 1790969

CUTOFF GRADE	TONNAGE ABOVE CUTOFF GRADE	AVERAGE GRADE	POUNDS U3O8	CUTOFF GRADE	TONNAGE ABOVE CUTOFF GRADE	AVERAGE GRADE	POUNDS U3O8
.010	624237	.143	1782729	.310	58243	.464	540576
.020	593846	.149	1773624	.320	54090	.476	514520
.030	559555	.157	1756566	.330	50271	.487	489792
.040	523326	.165	1731378	.340	46755	.499	466331
.050	486664	.175	1698625	.350	43516	.510	444072
.060	450644	.184	1659286	.360	40529	.522	422958
.070	415980	.194	1614518	.370	37774	.533	402929
.080	383110	.204	1565505	.380	35229	.545	383930
.090	352266	.215	1513371	.390	32878	.556	365908
.100	323543	.225	1459126	.400	30704	.568	348811
.110	296971	.236	1403623	.410	28693	.580	332590
.120	272492	.247	1347605	.420	26830	.591	317198
.130	250007	.258	1291679	.430	25103	.603	302592
.140	229400	.269	1236335	.440	23502	.614	288729
.150	210546	.281	1181955	.450	22016	.626	275569
.160	193316	.292	1128833	.460	20637	.637	263074
.170	177583	.303	1077183	.470	19354	.649	251209
.180	163222	.315	1027159	.480	18162	.661	239939
.190	150116	.326	978888	.490	17053	.672	229233
.200	138155	.337	932468	.500	16021	.684	219059
.210	127237	.349	887927	.510	15058	.695	209390
.220	117269	.360	845270	.520	14162	.707	200198
.230	108162	.372	804484	.530	13325	.718	191457
.240	99839	.383	765545	.540	12545	.730	183144
.250	92227	.395	728413	.550	11816	.742	175235
.260	85262	.406	693041	.560	11135	.753	167710
.270	78884	.418	659377	.570	10498	.765	160547
.280	73039	.429	627361	.580	9902	.776	153728
.290	67679	.441	596931	.590	9345	.788	147235
.300	62760	.453	568024	.600	8823	.799	141049

FIGURE 8. *Example of computer output of statistical analysis*

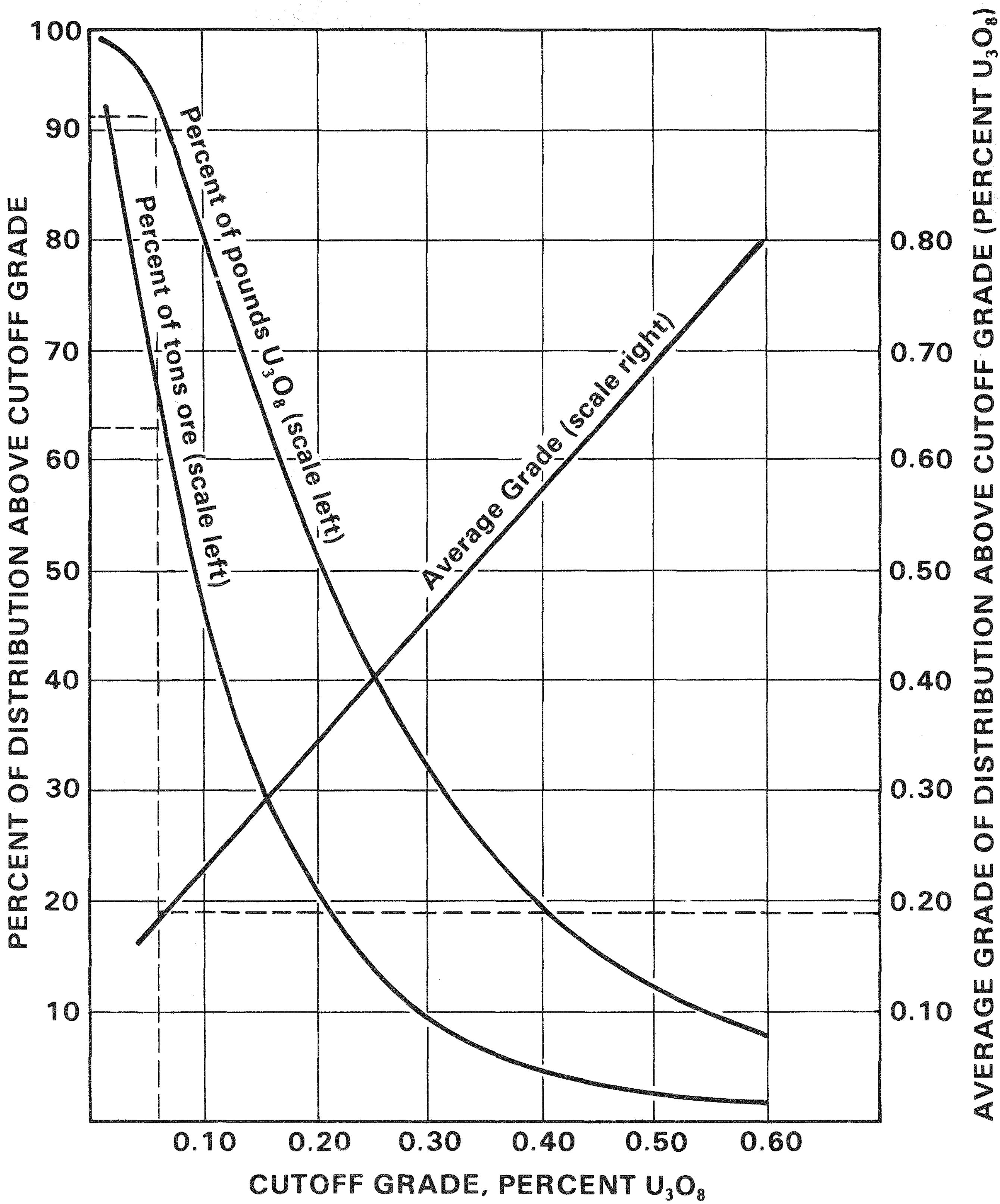


FIGURE 9. *Grade tonnage distribution*

TABLE 6. *Comparison of reserves estimated by the statistical method vs. production*

Prop.	Estimate [1/] Tons	Av. Gr.	Lbs U_3O_8	Production Tons	Av. Gr.	Lbs U_3O_8	Ratio Prod. lbs/Res. lbs	Drill-Hole Spacing
A	71,500	0.14	200,000	75,000	0.14	210,000	1.05	100′
B	1,235,000	0.19	4,700,000	1,256,000	0.20	5,024,000	1.07	150′
C	190,500	0.14	522,000	181,000	0.14	507,000	0.97	150′
D	507,300	0.23	2,334,000	519,000	0.23	2,387,000	1.02	150′
E	152,500	0.19	580,000	156,000	0.19	608,000	1.05	150′
F	380,700	0.25	1,900,000	382,000	0.25	1,910,000	1.01	100/150′
G	522,000	0.15	1,566,000	567,000	0.15	1,701,000	1.08	150′
H	1,200,000	0.24	5,760,000	1,220,000	0.24	5,856,000	1.02	100′
I	1,045,000	0.22	4,600,000	1,000,000	0.22	4,400,000	0.96	100′
J	80,000	0.24	383,000	79,000	0.24	386,000	1.01	50/100′
	5,384,500	0.21	22,545,000	5,435,000	0.21	22,989,000	1.02	

1/ Reserve estimates at grades equal to production grades.

For comparative purposes, the estimates of reserves were selected from grade-tonnage distributions as shown in figure 8 at grade levels equal to production grades. A close agreement is apparent. In other methods of reserve calculation, this comparison can be made only by repeated calculations at varying cutoffs, until the average grade of the reserve agrees with the production grade.

The statistical method of reserve estimation permits a deposit to be represented as a statistical model with cutoffs of 0.01 to 0.60 percent U_3O_8, thus permitting simplified analysis for practically all economic conditions. If changes in mining or milling costs require changing the cutoff grade for a deposit, the tonnage and average grade of the new reserve at the new cutoff can immediately be redetermined from the statistical model with no further analysis. The statistical method presents a complete picture of the grade-tonnage distribution of a deposit throughout the range of economic interest, and permits rapid, efficient, and more comprehensive evaluation. An example provided in figure 9 shows that, at a cutoff grade of 0.07 percent U_3O_8, nearly 91 percent of the pounds of U_3O_8 in the deposit are contained in 62 percent of the tons of material having an average grade of 0.19 percent U_3O_8. Another example, not illustrated, is that 9 percent of the deposit (tons of material) contains nearly one-third of the pounds of U_3O_8 at a 0.30 percent U_3O_8 grade cutoff.

Geostatistical Methods

GJO is currently developing computer procedures that will employ geostatistical methods utilizing the theory of regionalized variables. These techniques should improve: (1) estimates of grade-tonnage distributions, (2) evaluations of the adequacy of drill-hole spacings for reserve estimation, (3) better definition as to the reliability of reserve estimates, and (4) estimates of reserves with varying sizes of sample units and minable blocks, especially for the higher cost categories. Geostatistical methodologies should also help reduce the so-called "disappearing-ore problem" that may arise when initial estimates of grades for large blocks of reserves are based on wide-spaced sample points, and subsequent mining grade control is based on a much closer sample spacing.

Comparison of Estimation Methods

One advantage of the statistical method ORSAC for estimating reserves is that it is less sensitive to the number of samples and hole spacings than other commonly used methods for estimation. This feature is especially useful during the early phases of development of a deposit when there are relatively few samples and a maximum of unknowns. Table 7 shows the comparison of reserve estimates at three different cutoff grades for three methods of estimation: (1) general outline, (2) polygonal (a method commonly used outside GJO), and (3) statistical (ORSAC), based on a common data base for an area with a small number of irregularly spaced drill holes. Estimates were made for three levels of density of drill holes—for 10 holes that were initially drilled on a random pattern, for the nine fill-in holes that were drilled later, and for all 19 holes. The general outline and polygonal methods give estimates for the 10-hole and for the nine-hole patterns in value ranges from −13 percent to +7 percent of the estimates for the complete 19-hole pattern. The estimates using the statistical method (ORSAC) for the same sets of data are within a ±2-percent range.

OUTLOOK FOR 1980

The continued depletion of lower cost reserves due to increases in production costs during the past year will be reflected in the January 1, 1980, reserve figures. Environmental, health and safety, and other regulations and constraints, in conjunction with a high rate of inflation, have added substantially to costs. Consequently, the January 1, 1980, reserve estimates for the $15 and $30 categories will decrease significantly. However, additions to reserves from new discoveries and from extensions of known deposits, should result in a net increase in the $50-reserve category.

Reserves are now being estimated for a $100-cost category, and these will be reported later in 1980. Results of exploration activities in the areas shown in figure 10 are expected to add significantly to the reserves. Evaluation of drilling results in the major districts shown in figure 1 will continue to add to reserves.

The uranium that would be available as a supply base for future nuclear requirements has been reported in GJO production-capability studies as units of mill concentrate produced. Reserves reported by GJO are estimates of the quantities of uranium in ore that are recoverable by mining; the estimates do not take mill recovery into account. DOE plans to continue reporting reserves as uranium in ore but also plans to provide estimates on the amount of concentrate that might be produced from these reserves.

TABLE 7. *Comparison of estimates by different computation methods*

Cutoff	Computation Method	Num. Holes	Tons (1000)	Grade % U_3O_8	Pounds U_3O_8 (1000)	Percent Of Base Estimate	Percent Deviation From Base Estimate
6′ @ 0.05% U_3O_8	Gen Outline	19	697	0.13	1,812	Base	Base
		10	708	0.12	1,699	94	− 6
		9	609	0.13	1,583	87	−13
	Polygonal	19	698	0.13	1,815	Base	Base
		10	738	0.12	1,771	97	− 3
		9	651	0.13	1,693	93	− 7
	ORSAC	19	807	0.12	1,937	Base	Base
		10	889	0.11	1,995	101	+ 1
		9	727	0.13	1,889	98	− 2
6′ @ 0.07% U_3O_8	Gen Outline	19	591	0.14	1,655	Base	Base
		10	588	0.14	1,646	99	− 1
		9	581	0.13	1,511	91	− 9
	Polygonal	19	633	0.14	1,772	Base	Base
		10	609	0.14	1,705	101	+ 1
		9	613	0.13	1,594	90	−10
	ORSAC	19	552	0.15	1,656	Base	Base
		10	601	0.14	1,683	102	+ 2
		9	506	0.16	1,619	98	− 2
6′ @ 0.12% U_3O_8	Gen Outline	19	329	0.17	1,119	Base	Base
		10	308	0.19	1,170	105	+ 5
		9	315	0.16	1,008	90	− 10
	Polygonal	19	337	0.17	1,146	Base	Base
		10	324	0.19	1,231	107	+ 7
		9	330	0.16	1,056	92	− 8
	ORSAC	19	256	0.23	1,178	Base	Base
		10	269	0.22	1,184	100	0
		9	247	0.24	1,186	101	+ 1

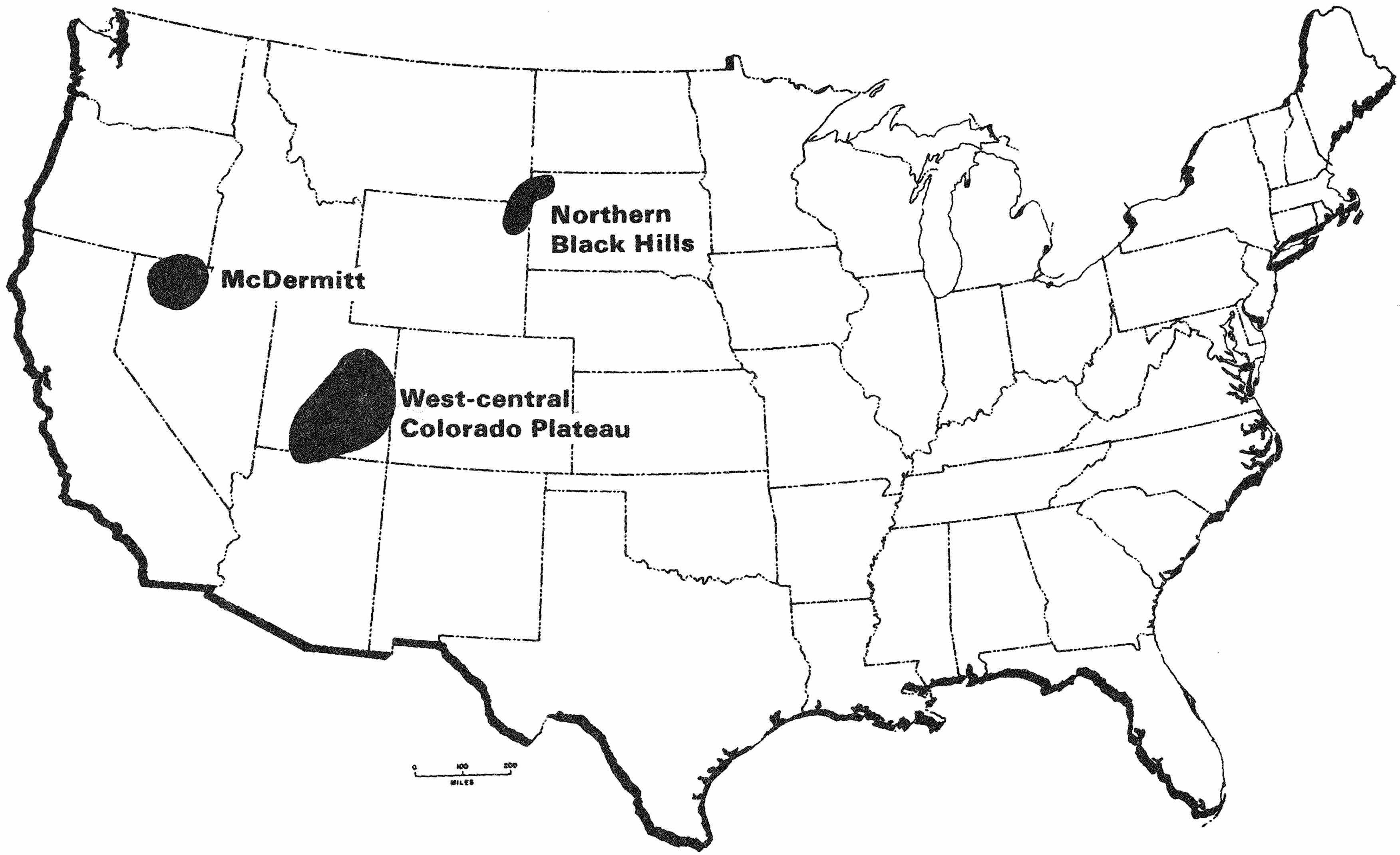


FIGURE 10. *Areas with expected significant additions to reserves*

POTENTIAL URANIUM RESOURCES

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October 1979

INTRODUCTION

Since 1948, the U.S. Department of Energy (DOE) and its predecessors, the Atomic Energy Commission (AEC) and the Energy Research and Development Administration (ERDA), have conducted active uranium resource assessment programs. The early resource assessments consisted of estimates of reserves for known uranium districts and of potential resources in general proximity to the areas assigned reserves. The resource base thus was confined to the western United States, chiefly to the Colorado Plateau, Rocky Mountains, and South Texas, where most known uranium districts were located. Beginning in the late 1960s, however, with forecasts of very large requirements for uranium to support projected nuclear power capacity, and questions about the need and timing of the development of the breeder reactor, increasing concern developed about the adequacy of domestic resources.

In 1974, the concern whether or not the nation was self-sufficient in uranium resources was translated into the approval and initial funding of the National Uranium Resource Evaluation (NURE) program. In June 1976, a preliminary report on this program was issued, followed in June 1979 by issuance of an interim report on NURE progress. These were milestone-type reports describing the progress on the NURE program and summarizing estimates of potential resources and their predicted locations in some detail. The next such report is scheduled for October 1980, when assessments of the most important resource areas in the United States are to be completed.

The DOE places its estimates of uranium resources into two broad classes, "reserves" and "potential." Reserves are the estimated quantities of uranium which occur in known deposits of such grade, quantity, configuration, and depth that they can be recovered at, or less than, a specified cost with state-of-the-art mining and processing technologies. Reserves essentially are synonymous with "Reasonably Assured Resources," as used by the Organization for Economic Cooperation and Development (OECD) Nuclear Energy Agency and the International Atomic Energy Agency. Potential resources of uranium are those surmised to occur in unexplored extensions of known deposits, in undiscovered deposits within or adjacent to uranium areas, or in other favorable areas. They are postulated to be discoverable and exploitable at specified costs. With the inception of the NURE program, the existing single-category classification of potential uranium resources was expanded to accommodate the wide variety of geologic environments under investigation in the nationwide assessment. The expanded classification separates the potential resources into three classes—probable, possible, and speculative. Definitions of each class are included at the end of this paper.

Estimates of "forward costs", which are costs not yet incurred, are used to assign the estimated resources to cost categories of $15, $30, and $50 per pound U_3O_8. For reserves, these are comprised of capital and operating costs of mining and milling, in present dollars, that would be incurred in production of the uranium. For potential resources in undeveloped areas, land acquisition, exploration, mine development, mill construction, etc. usually have not taken place; thus, costs of these activities are included in the forward cost estimates. For potential resources within known mining districts, however, some of these costs such as land acquisition and mill construction may have been incurred previously and would, therefore, be excluded from the forward costs. In the past, resources estimated by DOE's Grand Junction Office (GJO) have not been reduced by estimates of quantities that would be lost in the processing of the resources to produce U_3O_8 concentrate; however, this additional information will be provided in the future.

Since the 1978 Uranium Industry Seminar, reassessment of the domestic potential uranium resources has resulted in some significant changes. The pace of the NURE program has quickened resulting in an abundance of data that is being integrated into our evaluations and potential resource assessments. There also is more exploration activity by industry in frontier areas. As a consequence of the increase in available geologic information, some previous estimates have been modified, others have been eliminated, and new estimates have been made for a few new areas.

DOE is continuing to use subjective probability and geologic analogy in evaluating and assessing potential uranium resources. The methodology employs the following equation.

$$U_e = A \bullet F \bullet T \bullet G \div 100^*$$

where

U_e = uranium endowment in tons U_3O_8 above a cutoff grade of 0.01 percent U_3O_8

*A = area of favorable ground (a constant) in square miles

F = fraction of A underlain by (or associated with) uranium deposits

T = tons of uranium-bearing rock per unit area within the fractional area or volume

G = average grade of mineralized rock in percent U_3O_8 at a 0.01 percent cutoff grade

*If the estimator elects to view the favorable ground as a volume or length, then A is expressed in cubic or linear miles and T in tons of uranium-bearing rock per cubic or linear mile, and the computations are modified accordingly. Division by 100 merely reduces the grade (percentage U_3O_8) to a decimal fraction.

Use of the equation was described in my 1978 seminar paper, and a modified form of it also was discussed at this meeting by Dr. Robert C. Horton. A unique feature of the method is that it allows confidence limits to be assigned to the estimates while retaining maximum capability to utilize available geologic knowledge and the experience of the field geologists.

We are continuing our efforts to improve the estimative methodology for more reliable resource estimates, both in-house and by contracting with outside experts. For example, the University of Arizona is developing a computer-based geologic-decision model applicable for estimating the uranium endowment of areas favorable for uranium. A second study, also by the University of Arizona, was recently initiated to develop systems for assessing that part of the potential resources that could be discovered and exploited by optimized exploration, given specified economics and unconstrained markets. A second objective of the study is the estimation of potential resources based on a crustal-abundance endowment model.

Two types of models are being developed to provide a better understanding of the occurrence of uranium deposits and to help improve potential resource estimation. The first is a joint DOE and U.S. Geological Survey (USGS) pilot study of part of the Grants mineral belt, New Mexico, to provide a better geometric characterization of deposits in that area. The second effort will improve the geologic models of a variety of deposits in the United States and elsewhere in the world. Many completed studies, including clay alteration in the Grants mineral belt, uranium in alkaline volcanic rocks, and uranium in calcrete and gypcrete, have contributed materially to existing geologic models.

SUMMARY OF U.S. URANIUM RESOURCES AS OF JANUARY 1, 1979

Table 1 summarizes the January 1, 1979, estimates of reserves and potential resources in forward-cost categories of $15, $30, and $50 per pound U_3O_8. Figure 1 shows the trend of resource estimates during the past few years at costs of $30 and $50 per pound U_3O_8. Estimates of reserves and probable potential resources have consistently increased, possible potential resources decreased significantly from 1978 to 1979, and speculative potential resources have been relatively stable. A major reason for the decrease in possible resources is their transfer to the probable potential class. Also, some of the resources are no longer available at costs of $30 per pound U_3O_8 due to inflation and increased production costs; however, most of these resources remain in the $50 cost category. The DOE is now preparing estimates of resources in the $100 cost category to be included in the October 1, 1980, NURE report.

The distribution of the three classes of $50 per pound U_3O_8 potential resources for the 13 geographic regions is shown in figure 2. The same distribution of potential resources, production, and

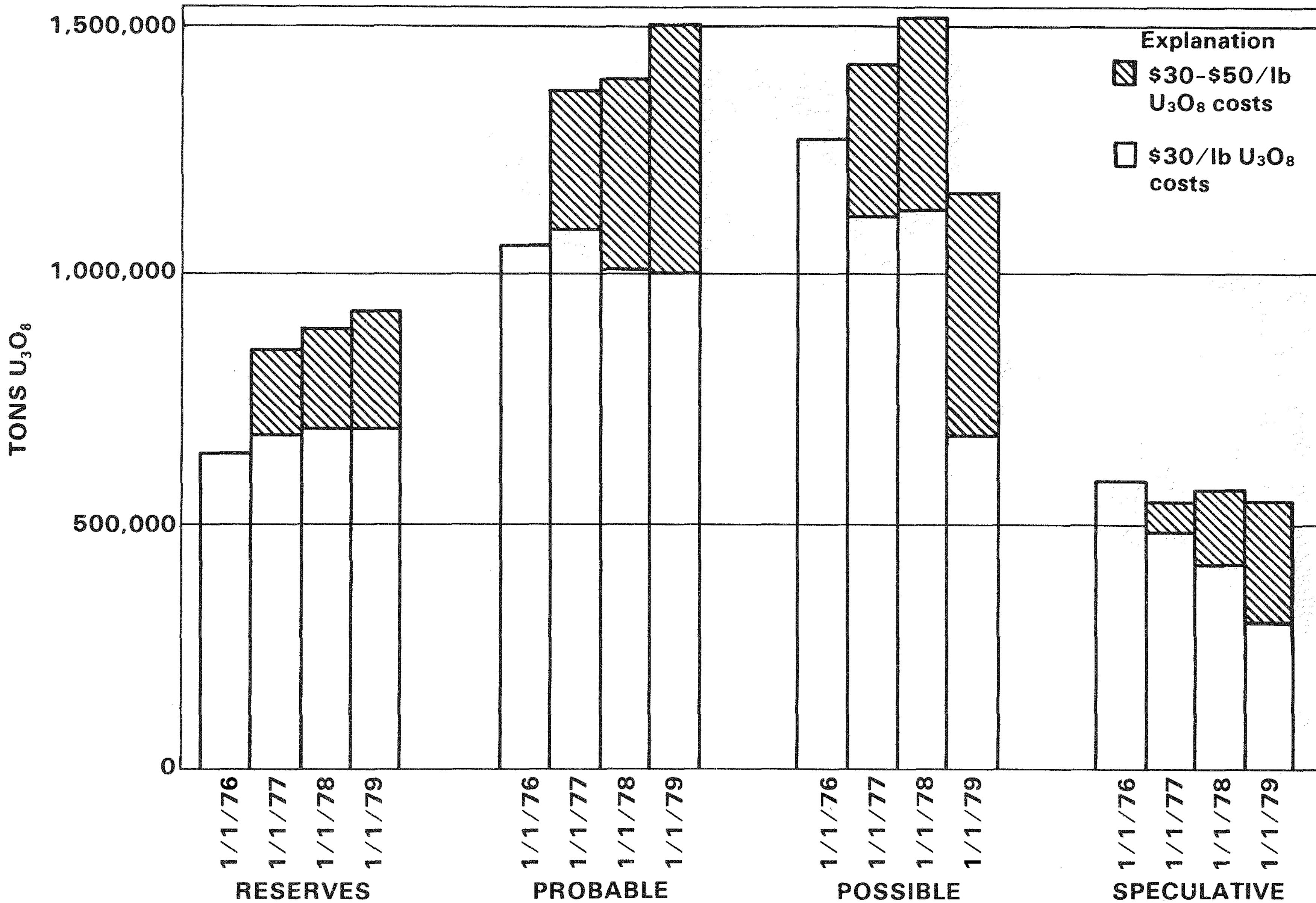

FIGURE 1. *Domestic uranium resource estimates*

TABLE 1. *United States uranium resources as of January 1, 1979*

$/lb U_3O_8 Cost Category	Tons U_3O_8 Reserves	Potential Resources Probable	Possible	Speculative
$15	290,000	415,000	210,000	75,000
$15–30 increment	400,000	590,000	465,000	225,000
$30	690,000	1,005,000	675,000	300,000
$30–$50 increment	230,000	500,000	495,000	250,000
$50	920,000	1,505,000	1,170,000	550,000

NOTE: Uranium that could be recovered as a byproduct of phosphate and copper mining through the year 2000 is estimated at 120,000 tons U_3O_8.

reserves, is listed in table 2. Resources in the Colorado Plateau far exceed those in the other regions in all classes. The Southern Canadian Shield is the only region with no production or current estimates of potential resources; however, favorable geologic settings for uranium deposits are believed to exist there.

Table 3 shows the distribution of the three classes of $50 per pound U_3O_8 potential resources by state. Probable potential resources have been estimated in 14 states, possible potential resources in 14 states, and speculative potential resources in 25 states. In all, potential resources have been estimated in 26 states. In the probable potential resource class, New Mexico leads with 550,000 tons, followed by Wyoming, Texas and Colorado. New Mexico also is first in the possible potential resource class, followed by Utah, Colorado, and Texas. In the speculative potential resource class, Oklahoma is first, followed by Colorado, Texas, and North Carolina.

TABLE 2. *Summary of uranium production, reserves, and potential resources by regions*

Region	Tons U_3O_8 Production to 1/1/79	Tons U_3O_8 ($50/lb) 1/1/79 Reserves	1/1/79 Potential Resources Probable	Possible	Speculative
(A) Colorado Plateau	228,200	498,700	767,000	696,000	30,000
(B) Wyoming Basins	74,500	280,200	364,000	73,000	32,000
(C) Coastal Plain	12,100	49,600	190,000	93,000	35,000
(D) Northern Rockies	}	25,300	42,000	36,000	52,000
(E) Colorado and Southern Rockies	17,500 (D–G)	31,900	62,000	114,000	41,000
(F) Great Plains	}	8,000	35,000	59,000	21,000
(G) Basin and Range	}	24,200	42,000	93,000	63,000
(H) Pacific Coast and Sierra Nevada	<1,000	2,100	2,000	6,000	6,000
(I) Central Lowlands	<1,000	0	†	†	111,000
(J) Appalachian Highlands	<1,000	0	†	†	127,000
(K) Columbia Plateaus	<1,000	0	†	†	32,000
(L) Southern Canadian Shield	0	0	†	†	†
(M) Alaska	<1,000	0	1,000	†	†
TOTAL	333,300	920,000	1,505,000	1,170,000	550,000

† Resources not estimated because of insufficient geologic data.

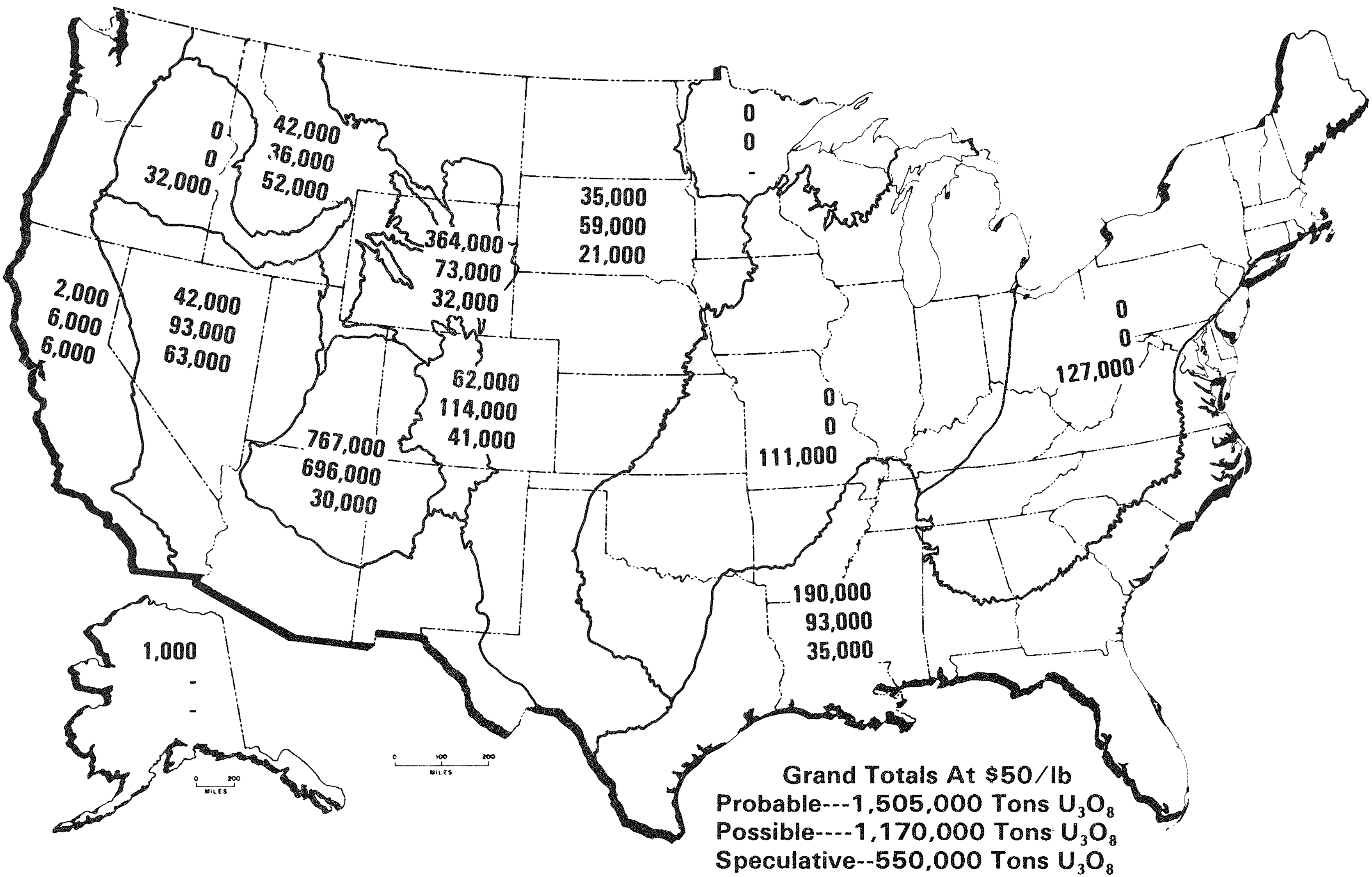

FIGURE 2. *Distribution of potential uranium resources $50/lb U_3O_8 as of January 1, 1979*

TABLE 3. *Distribution of \$50/lb U_3O_8 potential resources by state as of January 1, 1979.*

State	Probable	Possible	Speculative
Alaska	1,000	—	—
Arizona	48,000	60,000	10,000
Arkansas	—	—	3,000
California	22,000	18,000	7,000
Colorado	150,000	202,000	71,000
Connecticut	—	—	1,000
Idaho	—	7,000	40,000
Louisiana	—	—	<1,000
Massachusetts	—	—	<1,000
Montana	<1,000	9,000	28,000
Nevada	5,000	6,000	35,000
New Jersey	—	—	4,000
New Mexico	550,000	441,000	8,000
New York	—	—	30,000
North Carolina	—	—	55,000
North Dakota	7,000	4,000	<1,000
Oklahoma	—	—	97,000
Oregon	4,000	14,000	11,000
Pennsylvania	—	—	31,000
South Dakota	3,000	2,000	<1,000
Tennessee	—	—	1,000
Texas	188,000	92,000	57,000
Utah	122,000	220,000	7,000
Virginia	—	—	6,000
Washington	12,000	28,000	16,000
Wyoming	392,000	67,000	30,000
	1,505,000	1,170,000	550,000

Plate 1, from the interim NURE report published in June 1979, shows the location of the potential resources as of January 1, 1979. The red indicates those areas where probable and/or possible potential resources have been estimated, and the blue shows the locations of the speculative potential resources. As in the past, only speculative potential resources have been assigned to the eastern United States. Potential resources were assigned only to one small area in Alaska; however, recent encouraging results of industry exploration and NURE geologic studies have identified additional favorable areas in which potential resources may be assigned in the future.

Plate 2 is a supplement to the potential resources map (plate 1) and shows additional areas considered to be favorable for uranium deposits but for which there is insufficient data to estimate potential resources.

HIGHLIGHTS OF U.S. POTENTIAL RESOURCE INVESTIGATIONS

Colorado Plateau

The estimates of probable potential resources at \$50 per pound U_3O_8 for the Colorado Plateau were increased by 102,000 tons U_3O_8 during 1978. Approximately 11,900 tons U_3O_8 in ore were produced in this region in 1978, and almost 26,000 tons of \$50 per pound probable potential resources were converted to reserves.

The largest increase in estimates of the probable potential resources of the Colorado Plateau was in the Chaco Canyon area of the San Juan Basin. As shown in table 4, the increase was made partly at the expense of possible potential resources. The changes were based on the results of industry exploration and DOE geologic drilling downdip (north) from the main Grants mineral belt.

TABLE 4. *Impact of industry and NURE drilling on Chaco Canyon potential resource estimates during 1978*

	Tons U_3O_8 (cumulative)		
$50 Potential Resources	**Before Drilling**	**After Drilling 1-1-79**	**Total Changes**
Probable	118,000	189,000	+71,000
Possible	201,000	190,000	-11,000
TOTAL	319,000	379,000	+60,000

DOE estimates of $50 potential resources in the San Juan Basin have an economic depth limit of about 5,000 feet. Uranium resources probably occur at greater depths, but the cost of their recovery likely would exceed $50 per pound U_3O_8. A few uranium companies are drilling to depths greater than 5,000 feet in the southern part of the basin.

Elsewhere in the Colorado Plateau, estimates of probable potential resources were increased in the Paradox Basin of Utah and Colorado and in the Red Basin area of New Mexico and were decreased in the San Rafael Swell, Black Mesa Basin, and the Kaibab Uplift areas.

The 119,000 tons U_3O_8 decrease in estimated possible potential resources occurred mainly in areas of the San Juan Basin, Black Mesa Basin, and the Kaibab Uplift. The largest decrease was in the established districts in the San Juan Basin and was due largely to conversion of possible potential to either reserves or probable potential resources, based on the evaluation of industry exploration and NURE data. Minor increases in estimates of possible potential resources were made for the Paradox Basin, San Rafael Swell, and Red Basin. Estimates of speculative potential resources of the Colorado Plateau were reduced by 10,000 tons, primarily because of evaluation of additional industry exploration data for the Tertiary and Cretaceous sedimentary rocks in the San Juan Basin, and by conversion to other classes in the Red Basin.

Wyoming Basins

During 1978, the estimates of $50 probable potential resources were reduced slightly from 375,000 to 364,000 tons U_3O_8, primarily because of conversion of potential resources to reserves and reevaluation of prior estimates based on additional NURE and industry data. Wyoming Basins' production during 1978 was about 5,600 tons U_3O_8 in ore, while the conversion of potential resources to reserves was nearly 22,000 tons U_3O_8.

The estimates of possible potential resources were decreased 42,000 tons, mainly due to reevaluation of the Wind River Basin and the Washakie-Sand Wash Basin based on new geologic information.

Estimates of speculative potential resources in the Wyoming Basins were increased, primarily due to the addition of new potential resource areas in Precambrian crystalline rocks and Paleozoic and Tertiary sedimentary rocks in the Granite Mountains.

Texas Coastal Plain

The estimates of probable potential resources were increased by approximately 10,000 tons U_3O_8 during 1978, based on new NURE and industry data in the Duval and East Texas areas. In the Duval area, a greater lateral extent and thickness of the favorable units in the Goliad, Catahoula, and Oakville Formations were postulated for the Bruni, McBride, and Concepcion localities. In East Texas, the increase in estimates were for the Oakville and Catahoula Formations in the Muldoon locality. Production in this region during 1978, all from Texas, was 2,040 tons U_3O_8 in ore. Total reserves decreased by about 2,300 tons during 1978 due to reevaluation and subtraction of production.

The possible and speculative potential resources were unchanged during 1978. Doe currently is sponsoring a drilling program in the Falfurrias area of Brooks County, Texas, in an effort to determine the reliability of current estimates of probable and possible potential resources. The drilling will test the Catahoula Formation, as well as the Oakville and Goliad Formations, at greater depths than industry is expected to test in the short term.

Basin and Range

Estimates of potential resources in this region decreased in all classes. Reductions in the probable and speculative classes of 17,000 and 14,000 tons, respectively, were due primarily to reevaluations based on the results of NURE projects, recent industry exploration, and updated evaluations of economic availability.

A decrease in estimated possible potential resources of more than 150,000 tons U_3O_8 was made due to a substantial downward revision of potential estimates in the Spor Mountain area of west-central Utah. During 1978, DOE drilled 30 holes to test the continuity of uranium-bearing host rocks, particularly the uraniferous beryllium-bearing tuff, in which most of the estimated possible potential resources are carried and the Yellow Chief sandstone. The drilling indicated that the beryllium tuff unit is much more restricted in areal extent than was previously thought.

The recognition that numerous calderas and other volcanic-rock environments may be favorable for uranium in the Basin and Range has somewhat lessened the impact of the large decrease in estimated potential resources in the Spor Mountain area. Significant estimates of potential resources have been made in the McDermitt Caldera area of northern Nevada and southwestern Oregon, and similar environments in other portions of the region are being evaluated.

Currently, there are NURE drilling projects underway in the Date Creek area of west-central Arizona and in the Coso area of southeastern California. The drilling is to test the depths and lateral extent of uranium-bearing Tertiary sediments in which large estimates of potential resources have been made.

Colorado and Southern Rockies

Most of the increases in estimates of probable and possible potential resources were in the Tallahassee Creek area of central Colorado and were based on information from a continuing high level of industry activities.

Favorable environments have been identified by NURE geologic studies and limited industry drilling in Precambrian quartz-pebble conglomerates of the Medicine Bow and Sierra Madre Mountains of Wyoming. NURE drilling is being done in these areas in an attempt to define the geologically most favorable portions.

Great Plains

The estimated probable potential resources in the Great Plains were increased, primarily because of favorable results of industry activities in the Denver Basin. This increase was partially offset, however, by a decrease in the northern Black Hills. Possible potential resources decreased due to reevaluation in the Williston Basin and conversion of possible to probable potential resources in the Denver Basin. Estimates of speculative potential resources were decreased significantly based on preliminary results of NURE geologic favorability studies and industry exploration in the Bear Paw Mountains, Montana; Badlands, South Dakota; the Williston Basin, North Dakota; the Denver Basin, Colorado; and the Midland Basin, Texas.

Southeastern United States

NURE geochemical studies, conducted by the Savannah River Laboratory, have delineated a sizeable area of surficial uranium occurrences associated with gorceixite deposits centered in southwestern South Carolina that may constitute large low-grade resources. Although the extent of the occurrences has yet to be determined, uranium content in samples of gorceixite, a hydrated barium aluminum phosphate mineral, ranges from 80 to 850 parts per million. Further evaluation is required before any estimate of potential resources is possible.

Appalachian Highlands

Estimates of speculative potential resources for the Catskill Delta complex in Pennsylvania, the Grandfather Mountain area in North Carolina, the Reading Prong area in New York and New Jersey, and the Triassic Basins in the Piedmont Province were increased from 95,000 to 127,000 tons U_3O_8, based on NURE geologic studies, aerial and geochemical surveys, and industry-provided information.

DISTRIBUTION OF POTENTIAL URANIUM RESOURCES

Potential resources estimated by the DOE are categorized by geologic age, host-rock type, type of geologic occurrence, and average depth. The numerical distributions of the $50 per pound U_3O_8 potential resources in these categories are described below. The last previous presentation of these distributions of potential resources was in my 1976 seminar paper.

Age of Host Rocks

Distributions of the three classes of $50 per pound U_3O_8 potential resources by host rock age are shown in table 5. Ages of the host rocks range from Precambrian to Quaternary. Most of the potential resources in the probable and possible classes are assigned to host rocks of Jurassic and Tertiary ages. In the speculative class, most of the potential resources are assigned to host rocks of Paleozoic and Tertiary ages.

Figure 3 shows the geographic distribution by age of host rocks of areas for which probable and possible potential resources have been estimated. The host rocks are dominantly of Mesozoic and Cenozoic ages and are in or near uranium districts that have been prospected and explored since the 1950s. It should be noted that no probable or possible potential resources have yet been assigned to the eastern United States.

Paleozoic rocks with assigned probable and possible potential resources occur in the Colorado Plateau, the Colorado and Southern Rockies, and the Pryor Mountains area of Wyoming and Montana. Small areas of probable and possible potential resources in Precambrain rocks are located in the Northern Rockies, the Colorado and Southern Rockies, and the Southern Basin and Range.

Figure 4 shows the geographic distribution of areas with estimated speculative potential resources by host-rock age. In the western United States, Cenozoic and Mesozoic host rocks predominate. Development of new favorable data by the NURE program and private industry has resulted in the estimation of speculative potential resources for selected sedimentary rocks of the Triassic Newark Group in structural basins in Massachusetts, Connecticut, New Jersey, Pennsylvania, Virginia, and North Carolina. The distribution of Paleozoic rocks in which speculative potential resources have been estimated are dominated by Devonian to Upper Mississippian sedimentary rocks in the Appalachian Plateau in Pennsylvania, New Jersey, and New York, principally in the Catskill Delta sequence. Precambrian rocks with speculative potential resources are primarily in crystalline terranes of the Reading Prong and Blue Ridge complexes in the Appalachian Highlands, the Southern Basin and Range, the Colorado and Southern Rockies, and the Northern Rockies regions.

Figure 5 shows the ages of the rocks in areas regarded as favorable, but where data are inadequate for estimation of potential resources. Favorable Mesozoic and Cenozoic rocks predominate in the conterminous United States and Alaska. Favorable Paleozoic rocks are confined to the eastern and southern United States while favorable Precambrian rocks are in the Southern Canadian Shield, East Texas, the Rocky Mountains, and the Southwest.

Type of Host Rock

The distribution of $50 per pound potential resources by host-rock type are shown in table 6. Potential resources are estimated for a wide range of lithologic types of host rocks, although sandstones are estimated to contain the largest

TABLE 5. *Distribution of potential resources at $50/lb U_3O_8 by age of host rock as of January 1, 1979*

Age	Probable		Possible		Speculative	
	Tons U_3O_8	(%)	Tons U_3O_8	(%)	Tons U_3O_8	(%)
Quaternary	0		0		23,000	(4)
Tertiary	634,000	(43)	371,000	(32)	167,000	(30)
Cretaceous	30,000	(2)	72,000	(6)	25,000	(5)
Jurassic	668,000	(44)	529,000	(45)	1,000	(<1)
Triassic	60,000	(4)	148,000	(12)	48,000	(9)
Paleozoic	61,000	(4)	20,000	(2)	199,000	(36)
Precambrian	52,000	(3)	30,000	(3)	87,000	(16)
TOTAL	1,505,000	(100)	1,170,000	(100)	550,000	(100)

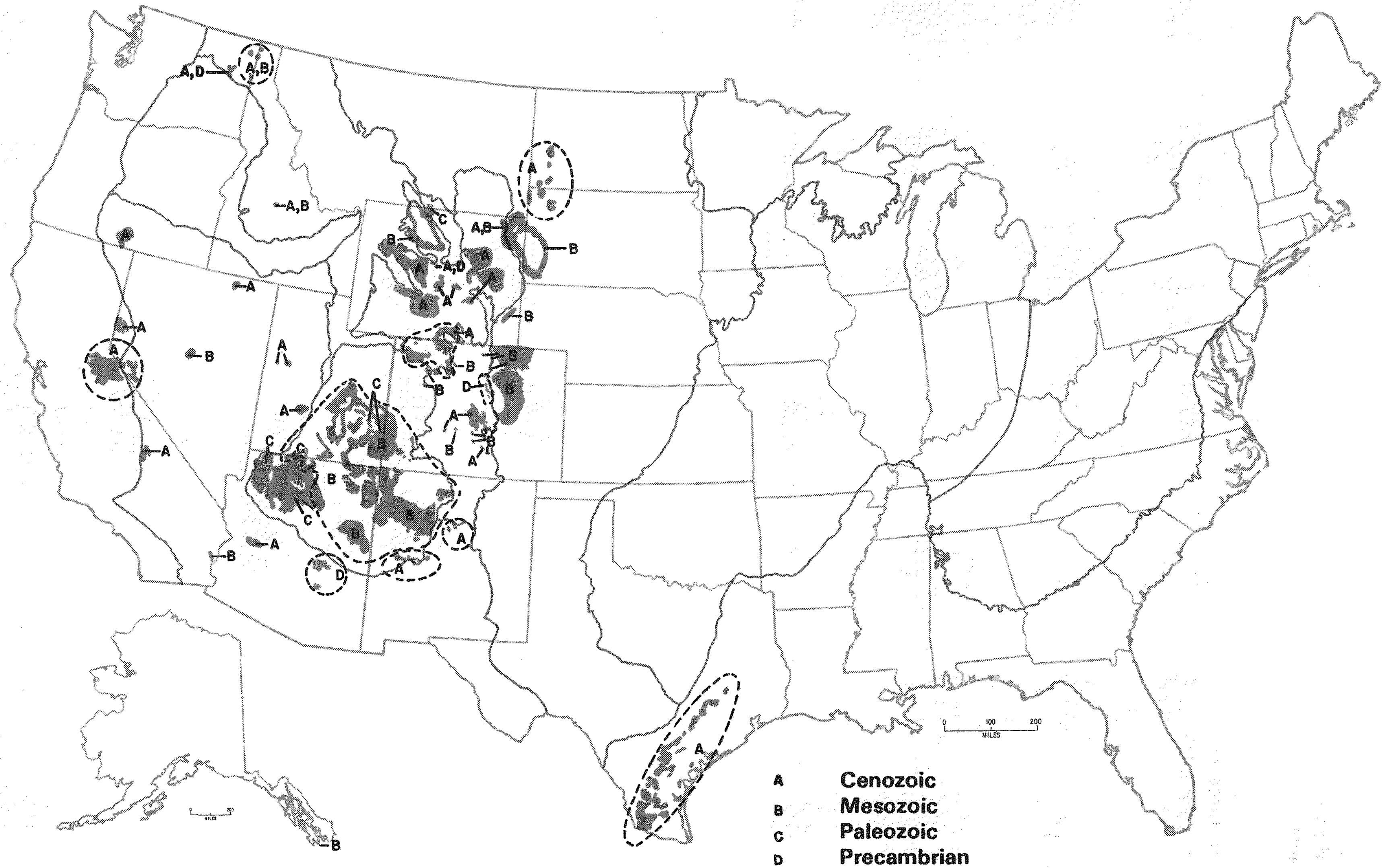

FIGURE 3. *Distribution of probable and possible potential resources by age of host rock*

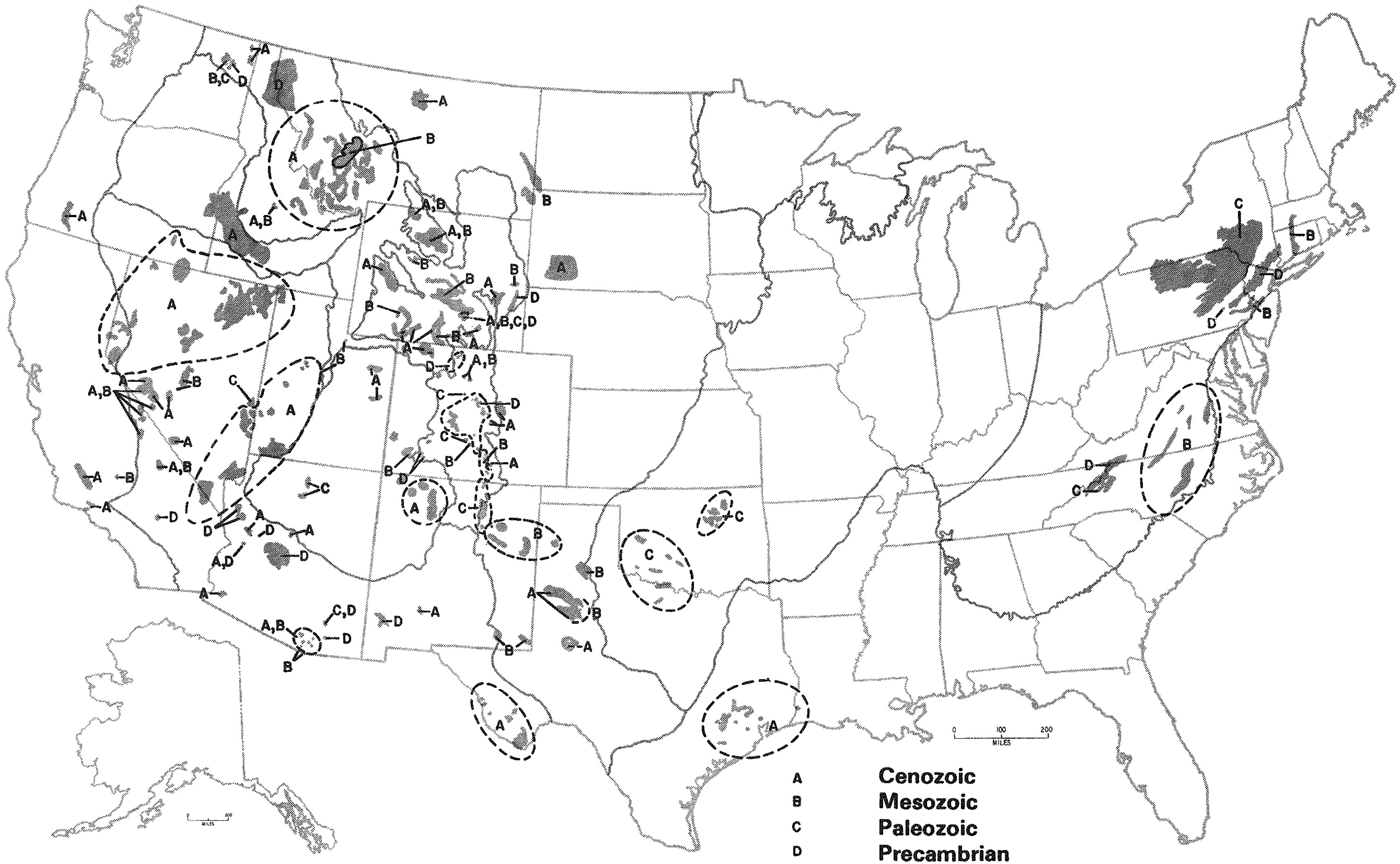

FIGURE 4. *Distribution of speculative potential resources by age of host rock*

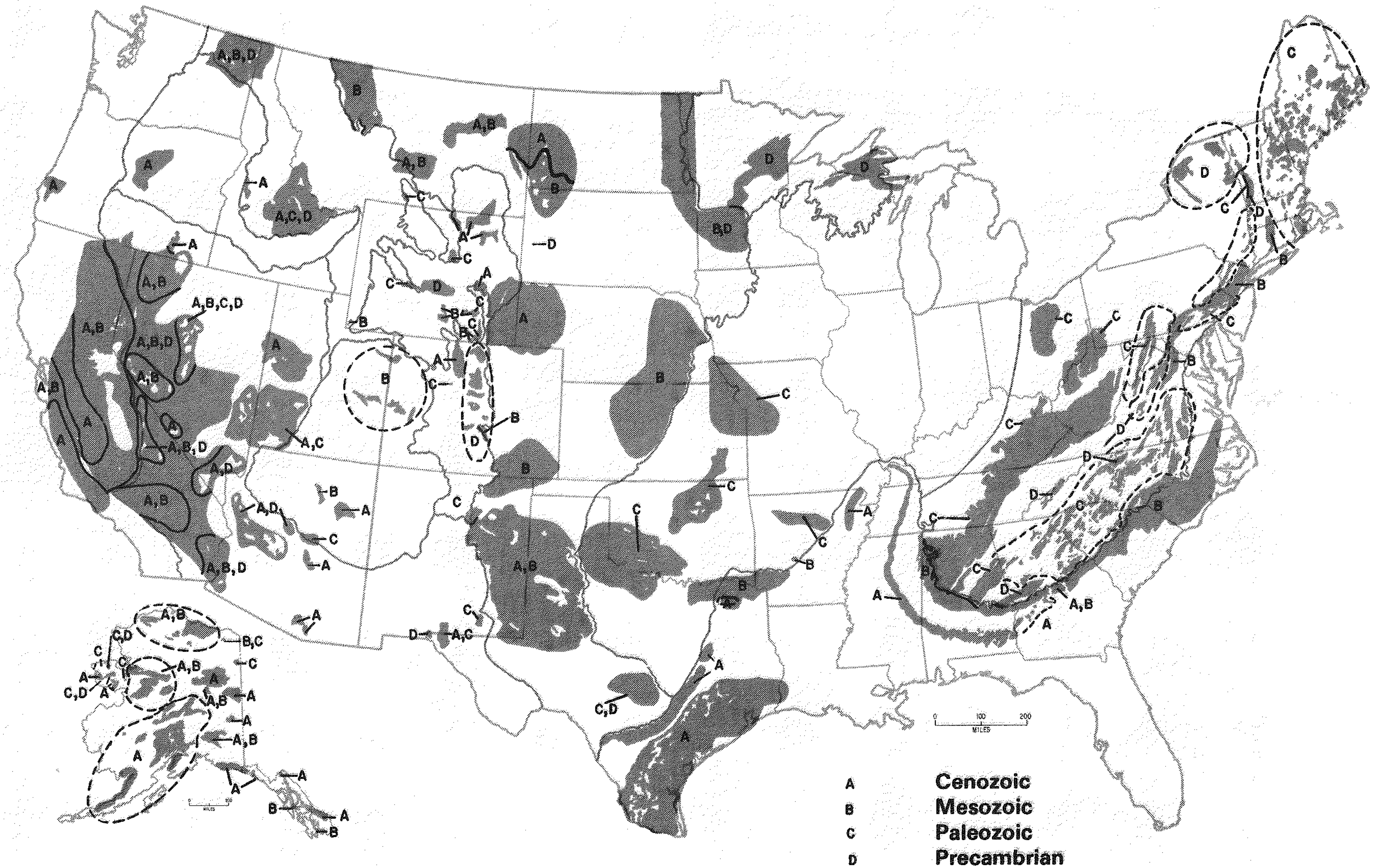

FIGURE 5. *Age of host rock in favorable areas*

TABLE 6. *Distribution of potential resources at $50/lb U_3O_8 by type of host rock as of January 1, 1979*

Host Rock	Probable Tons U_3O_8	(%)	Possible Tons U_3O_8	(%)	Speculative Tons U_3O_8	(%)
Sandstone	1,365,000	(91)	1,039,000	(89)	365,000	(66)
Conglomerate	40,000	(3)	37,000	(3)	32,000	(6)
Granitic and metamorphic	75,000	(5)	47,000	(4)	131,000	(24)
Volcanic	8,000	(<1)	43,000	(4)	16,000	(3)
Limestone	8,000	(<1)	-	-	5,000	(1)
Lignite	9,000	(<1)	4,000	(<1)	1,000	(<1)
TOTAL	1,505,000	(100)	1,170,000	(100)	550,000	(100)

quantities, with granite and metamorphic rocks next in importance.

Type of Geologic Occurrence

The geographic distribution of areas containing probable and possible potential resources by type of geologic occurrence is shown in figure 6. Most of the estimated probable and possible potential resources are in sandstone-type deposits in sandstones and conglomerates in the Colorado Plateau, Wyoming Basins, Texas Coastal Plain, Great Plains, Basin and Range, and Sierra Nevada. Veins and related types occur in a variety of rock types scattered throughout the western United States, principally in the Basin and Range, Colorado and Southern Rockies, and Northern Rockies. The Kaibab Plateau area in the southwestern Colorado Plateau is favorable for deposits in collapse pipe structures, which are grouped in the vein category. Minor quantities of probable and possible potential resources are estimated for limestones in the southern San Juan Basin and the Northern Rockies and for lignitic host rocks in the northern Great Plains and the Texas Coastal Plain.

The distribution of speculative potential resources by type of occurrence is shown in figure 7. Speculative potential resources of the sandstone type are assigned to various geologic settings throughout the western states, in the Appalachian Highlands, and in New England. Speculative potential resources in veins are concentrated largely in the Northern Rockies, Basin and Range, Colorado and Southern Rockies, and the Appalachian Highlands. Areas with speculative potential resources assigned to limestone are restricted to small areas of the Northern Rockies and the southern Central Lowlands, while those assigned to lignites are limited chiefly to the northern Great Plains and the Texas Coastal Plain. Figure 8 shows the distribution by type of occurrence of additional areas tentatively identified as favorable for uranium deposits.

Average Depth of Host Rocks

The distribution of potential resources by average depth is shown in table 7. In each potential class, more than 70 percent of the estimated potential resources are assigned to depths shallower than 2,000 feet, although in the probable

TABLE 7. *Distribution of potential resources at $50/lb U_3O_8 by depth as of January 1, 1979*

Average Depth (ft)	Probable Tons U_3O_8	(%)	Possible Tons U_3O_8	(%)	Speculative Tons U_3O_8	(%)
0-500	395,000	(26)	180,000	(15)	189,000	(34)
500-1,000	450,000	(30)	274,000	(24)	66,000	(12)
1,000-2,000	222,000	(15)	385,000	(33)	202,000	(37)
2,000-3,000	61,000	(4)	104,000	(9)	81,000	(15)
3,000-4,000	242,000	(16)	167,000	(14)	2,000	(<1)
4,000-5,000	135,000	(9)	60,000	(5)	10,000	(2)
TOTAL	1,505,000	(100)	1,170,000	(100)	550,000	(100)

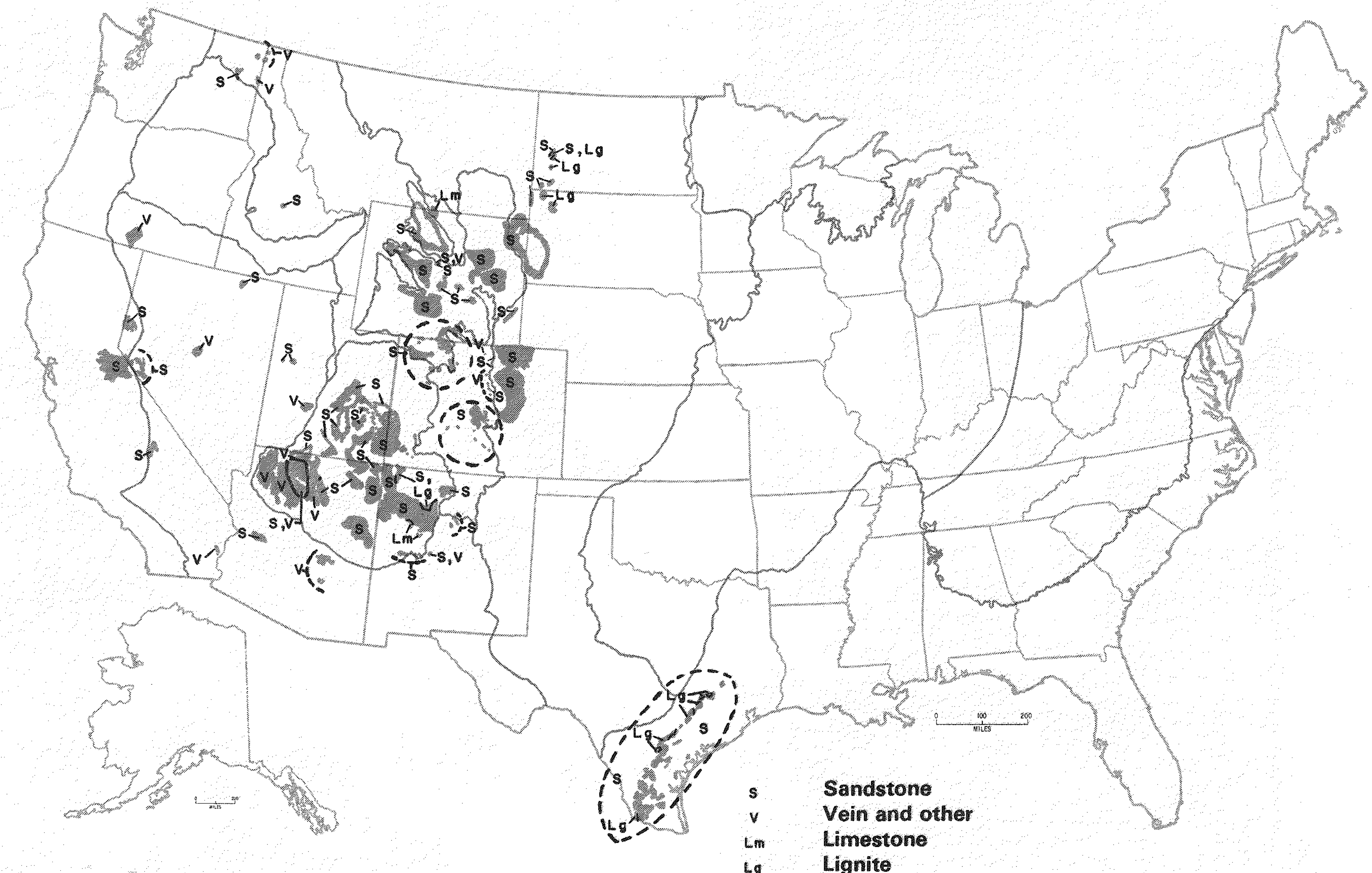

FIGURE 6. *Distribution of probable and possible potential resources by type of geologic occurrence*

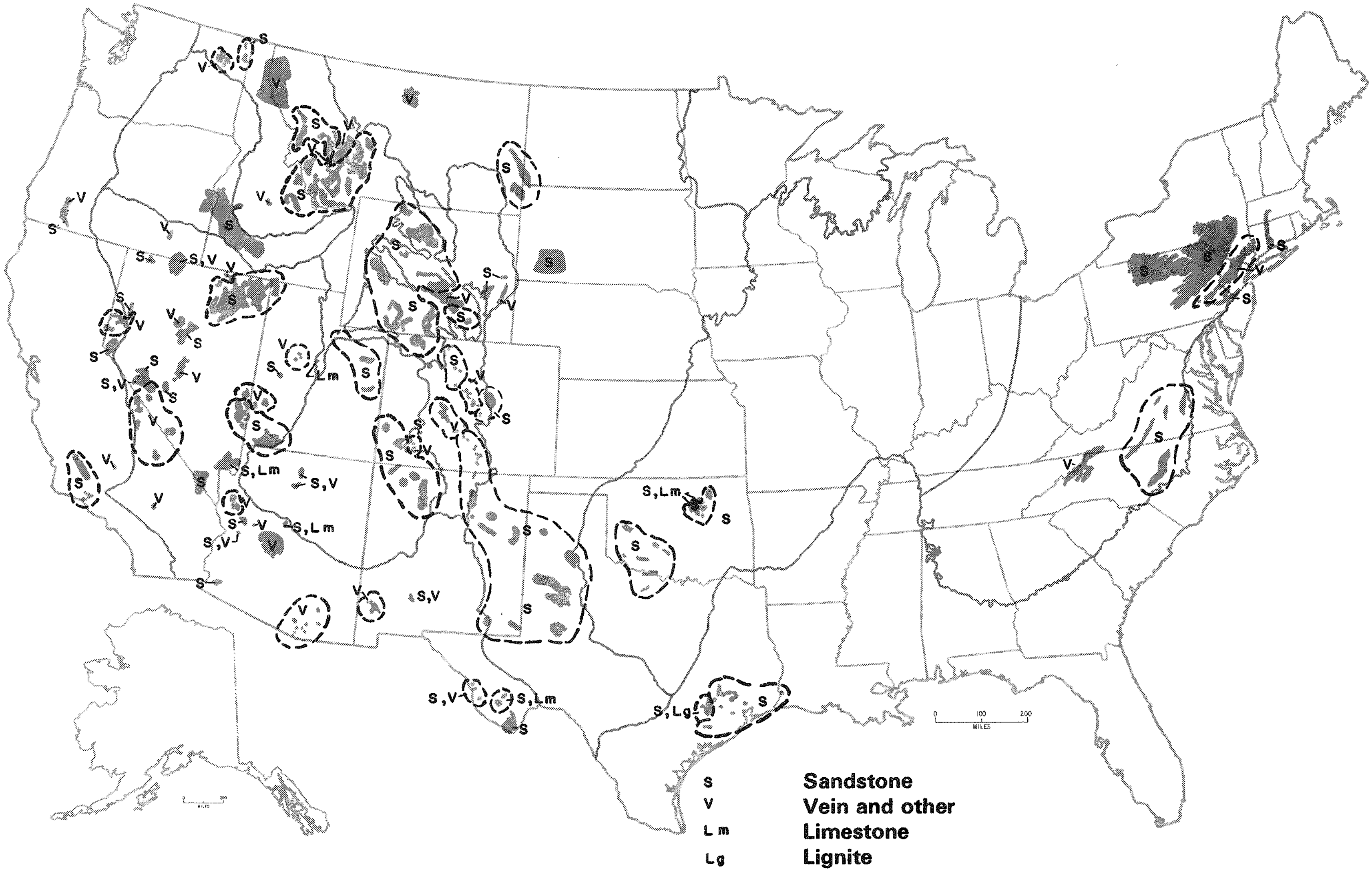

FIGURE 7. *Distribution of speculative potential resources by type of geologic occurrence*

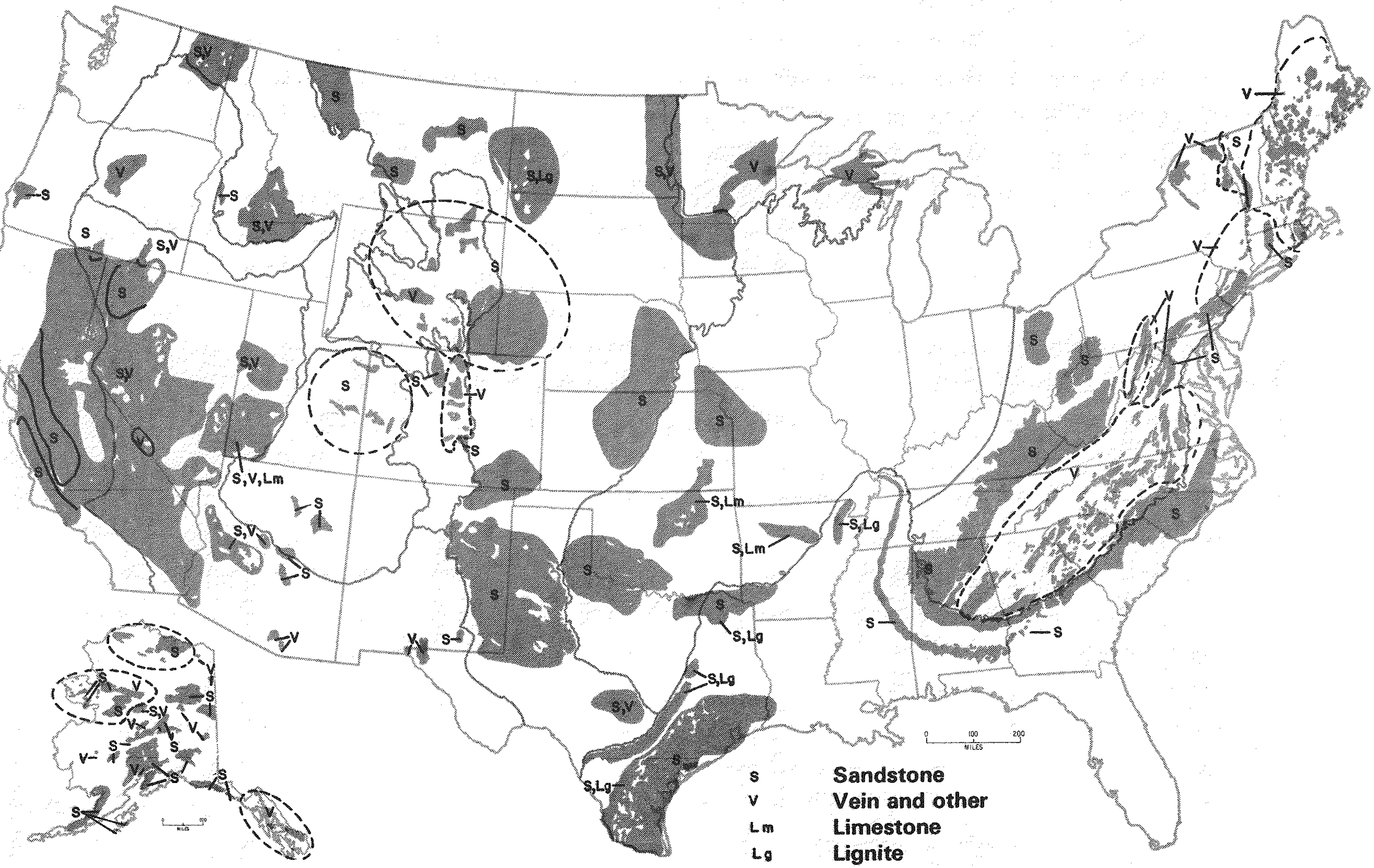

FIGURE 8. *Types of geologic occurence in the favorable areas*

and possible classes, significant tonnages are assigned to greater depths.

Figure 9 shows the geographic distribution of probable and possible potential resources by average depth. Depths generally are less than 2,000 feet except in the Colorado Plateau where potential resources are estimated for the Morrison Formation in the southern San Juan Basin to depths greater than 4,000 feet. Potential host rocks are as deep as 2,000 feet in the Texas Coastal Plain and in isolated areas in the Northern Rockies and Basin and Range regions. Probable and possible potential host rocks in the remainder of the western states are less than 1,000 feet.

Figure 10 shows the average depth of speculative potential resources. Pliocene and Miocene host rocks are assigned speculative potential resources to depths as great as 4,000 feet in the Snake River Basin of the Columbia Plateaus region. Most speculative potential host rocks in the Colorado Plateau, Basin and Range, and Wyoming Basins range in depth from a few feet to 1,000 feet. However, host rocks in a few areas in these regions are as deep as 2,000 feet. Most of the host rocks are at depths of 1,000 to 2,000 feet in the Texas Coastal Plain, Northern Rockies, Appalachian Highlands, and Great Plains.

Figure 11 shows the average depths to rock units considered favorable in areas where no estimates of potential resources have been made. In most of these areas, the favorable rocks are less than 1,000 feet. However, favorable geologic settings as deep as 2,000 feet have been recognized in the Northern Rockies, Basin and Range, Great Plains, Central Lowlands, Coastal Plain, and Appalachian Highlands. In addition, favorable rock units are as deep as 3,000 feet in the Central Lowlands and the Texas Coastal Plain.

OUTLOOK FOR 1980

The January 1, 1979, uranium resources were estimated by DOE geologists stationed in nine field offices distributed throughout the United States. A major goal of the NURE program is to evaluate and assess, by October 1, 1980, the potential uranium resources of the 116, 1-degree by 2-degree, priority quadrangles which contain all of the uranium reserves and most of the potential resources currently estimated by DOE. These quadrangles are being evaluated by Bendix Field Engineering Corporation, the USGS, state geological surveys, and subcontractors. In portions of the quadrangles where proprietary data is available, DOE geologists will continue to estimate the potential resources. DOE also will review all folios and potential estimates generated by the investigators.

As a result of the accelerated assessment program and the addition of a $100 per pound U_3O_8 category of estimated resources, we expect significant changes in the October 1, 1980, potential resources. Estimates of potential resources in the speculative class are expected to increase significantly as new environments and host rocks are recognized. Potential resources in the probable and possible classes also are expected to increase as a result of new exploration data developed by industry and by new data and concepts developed by the NURE quadrangle investigators.

DEFINITIONS OF CLASSES OF POTENTIAL RESOURCES

"Probable" potential resources are those estimated to occur in known productive uranium areas:

1. in extension of known deposits, or
2. in undiscovered deposits within known geologic trends or areas of mineralization.

"Possible" potential resources are those estimated to occur in undiscovered or partly defined deposits in formations or geologic settings productive elsewhere within the same geologic province or subprovince.

"Speculative" potential resources are those estimated to occur in undiscovered or partly defined deposits:

1. in formations or geologic settings not previously productive within a productive geologic province or subprovince, or
2. within a geologic province or subprovince not previously productive.

Note: "Productive" means that past production plus known reserves exceed 10 tons U_3O_8.

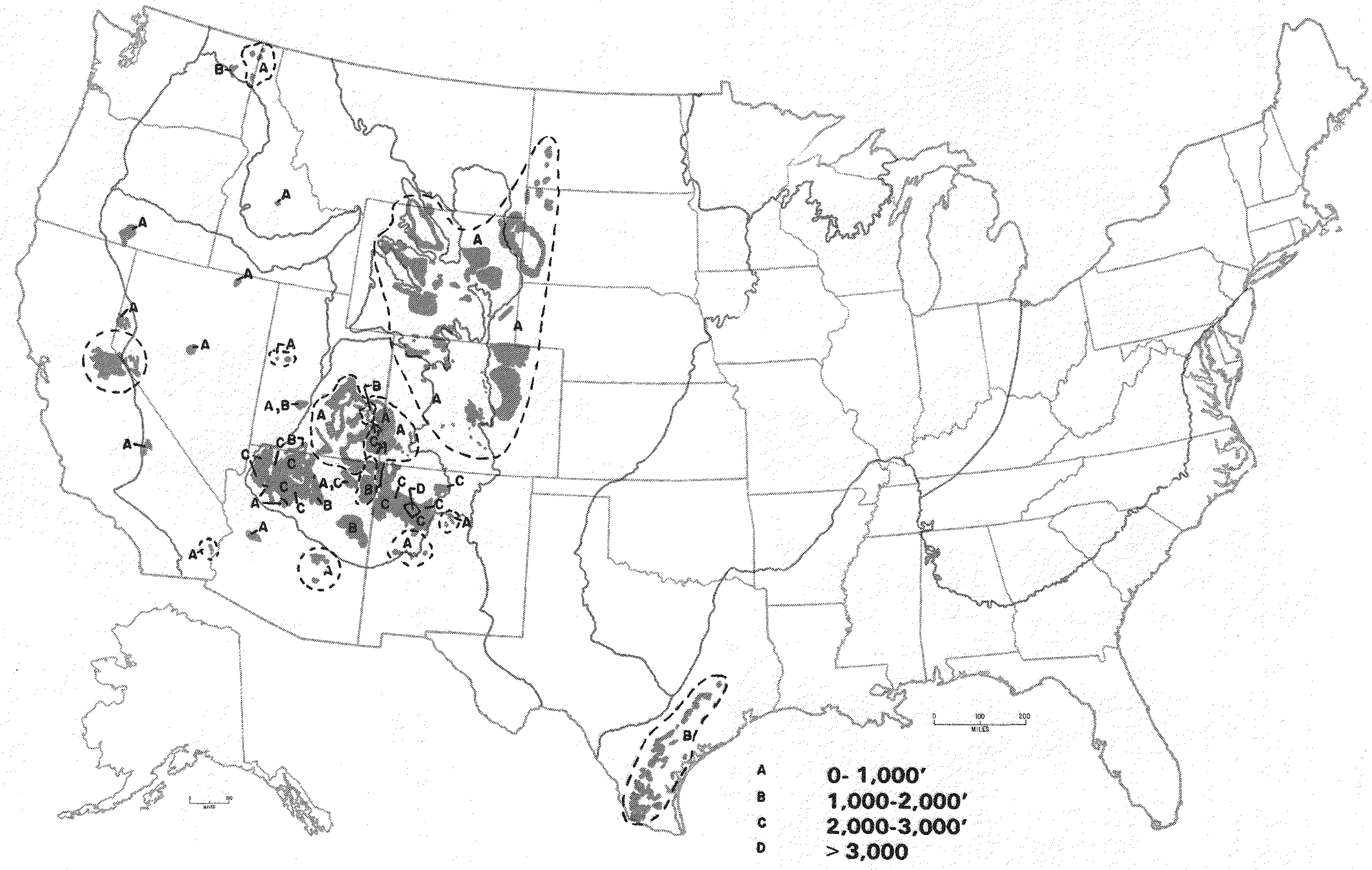

FIGURE 9. *Distribution of probable and possible potential resources by average depth of host rock*

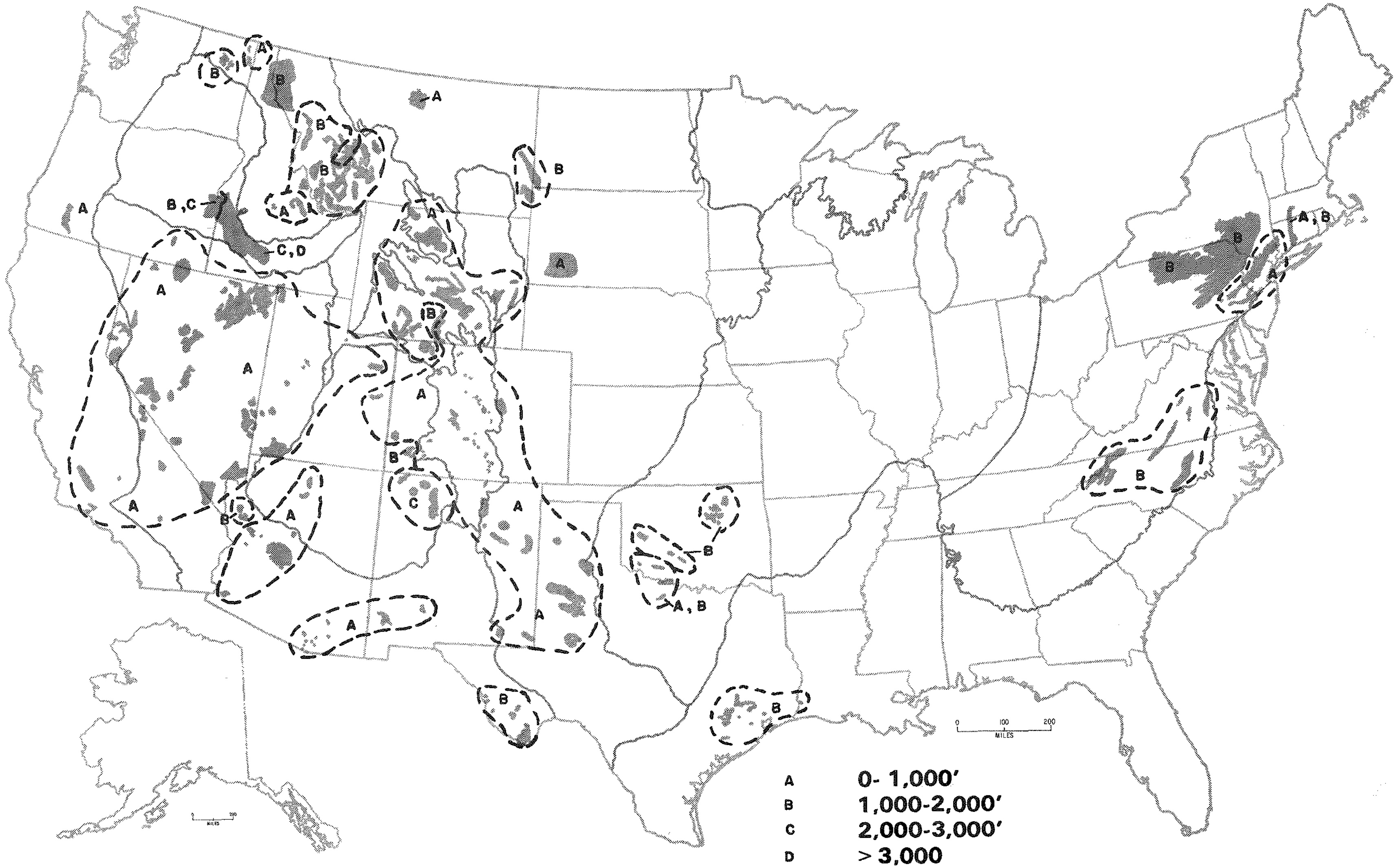

FIGURE 10. *Distribution of speculative potential resources by average depth of host rock*

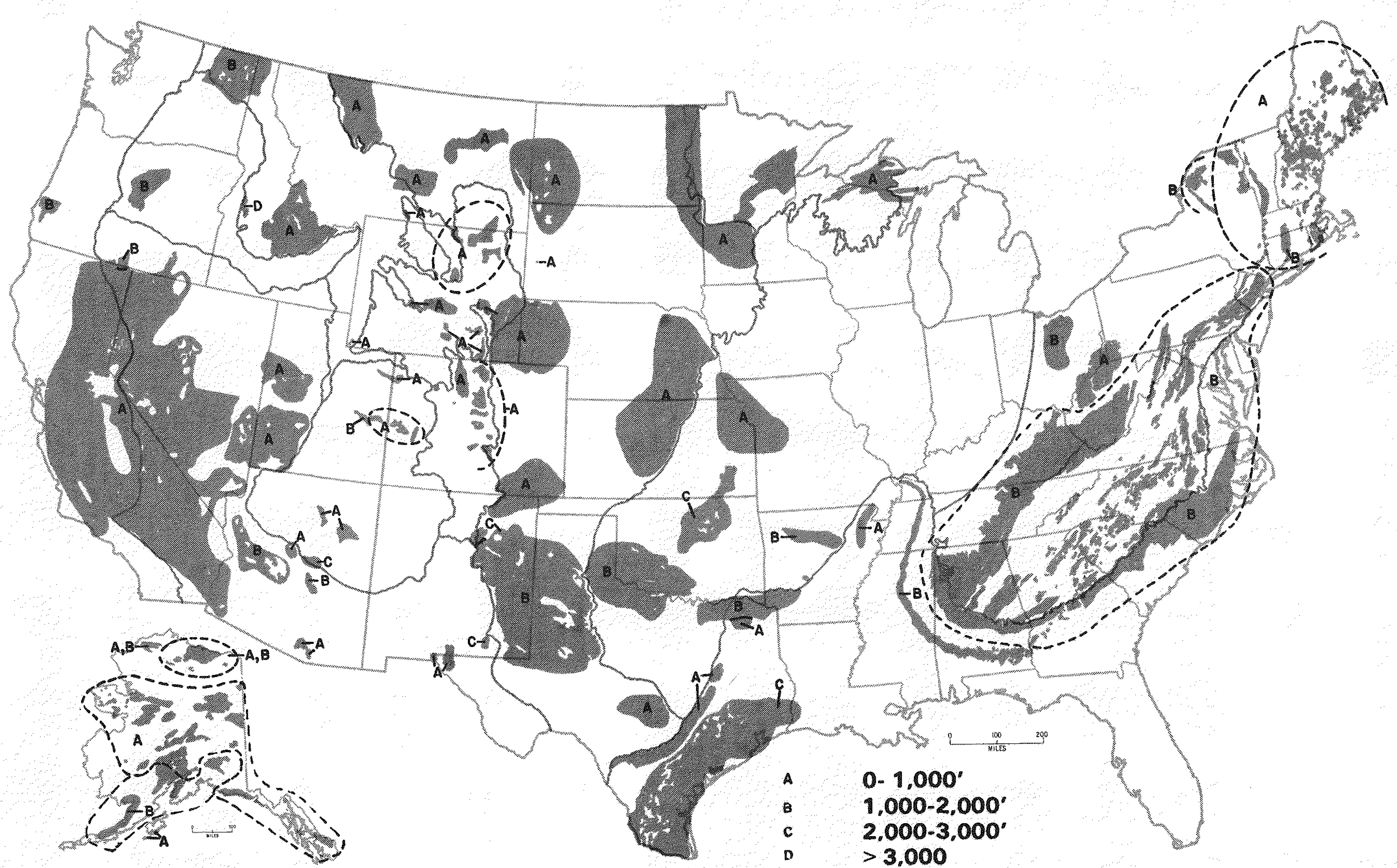

FIGURE 11. *Average depth of host rock in favorable areas*

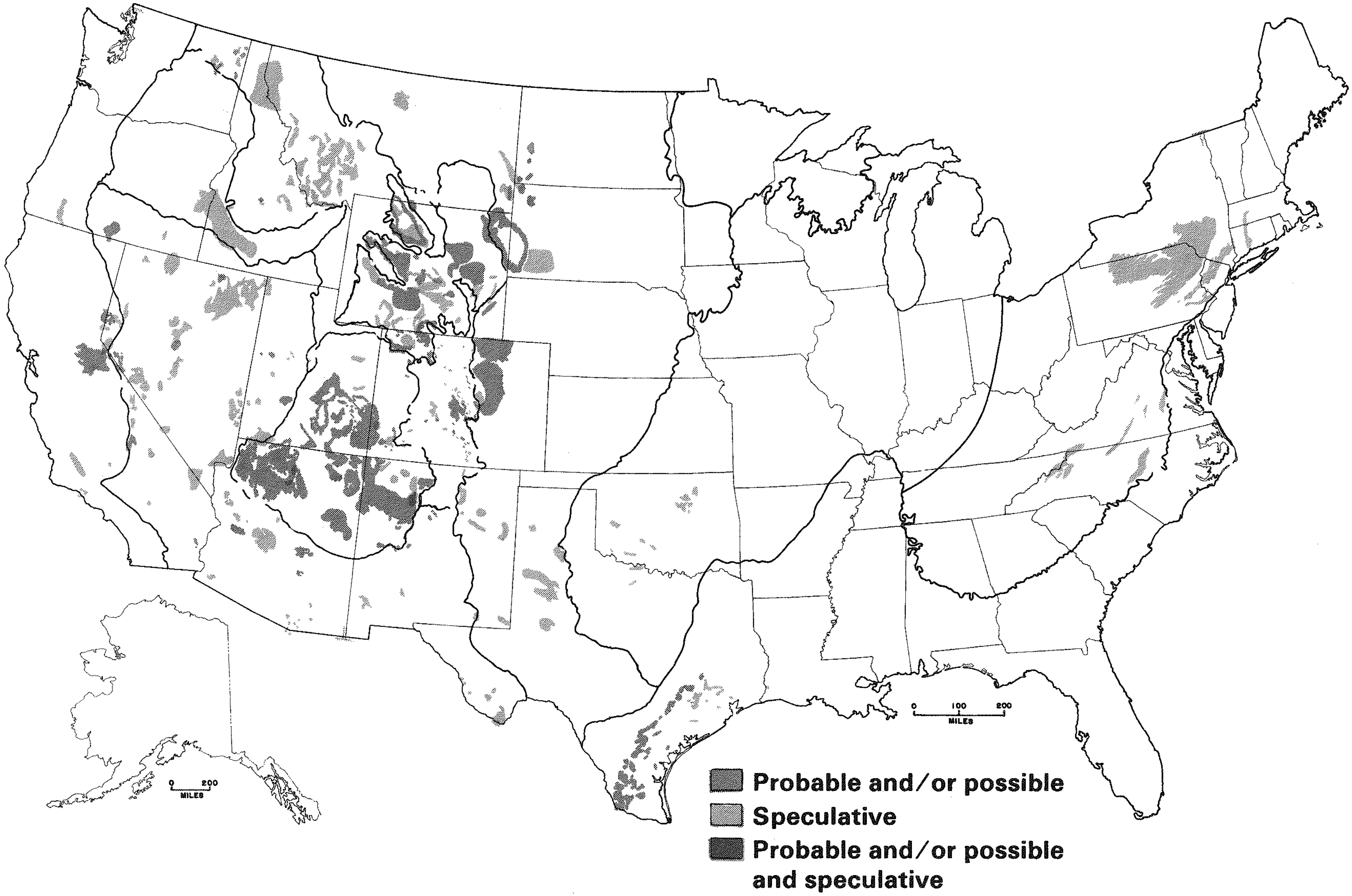

PLATE 1. *National uranium resource evaluation potential uranium areas*

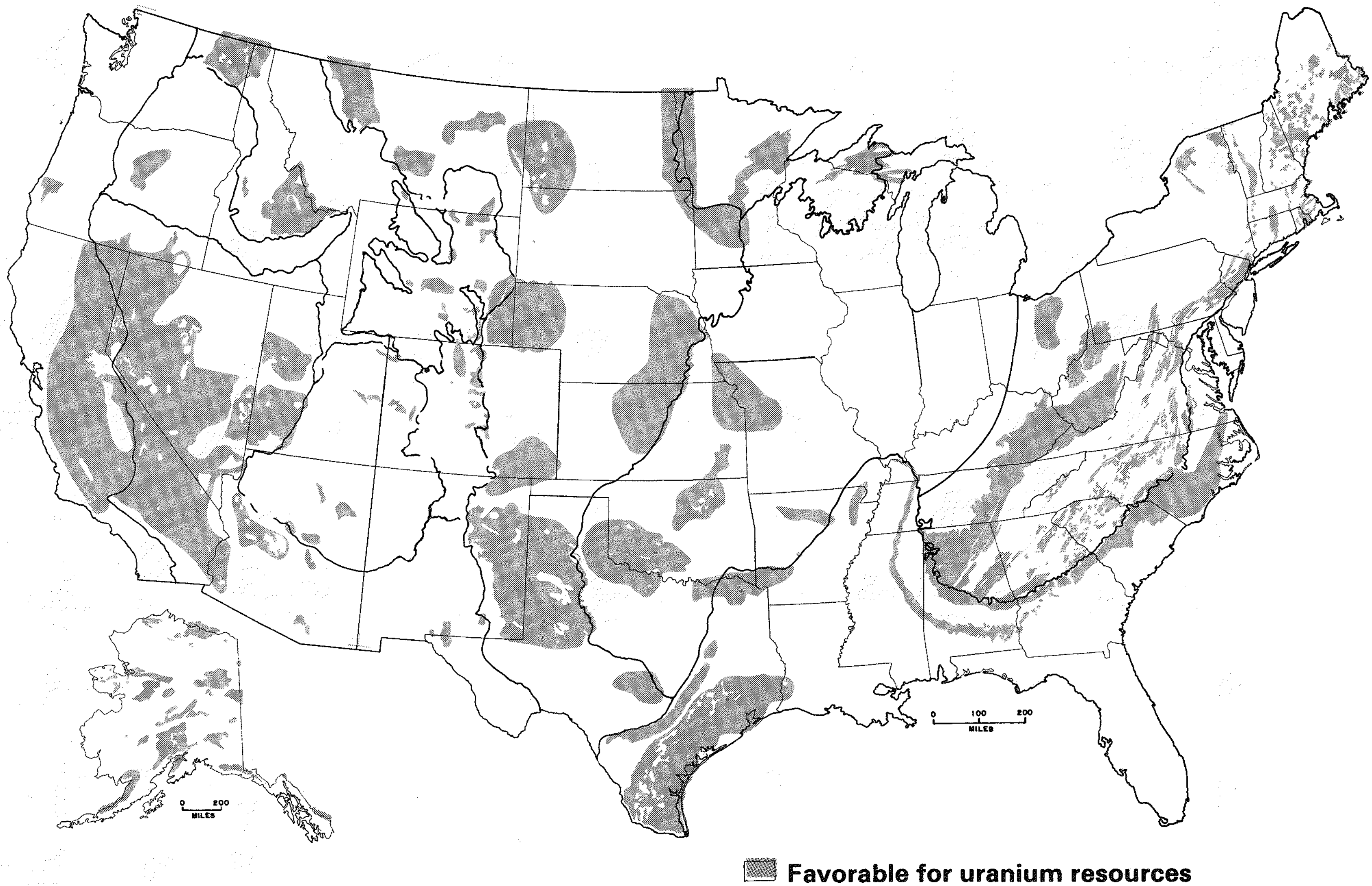

PLATE 2. *National uranium resource evaluation areas with favorable geology*

INDUSTRY EXPLORATION ACTIVITIES

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October 1979

INTRODUCTION

The momentum of U.S. uranium exploration in 1977 carried over into 1978 when surface drilling reached an all-time high of 47 million feet. However, drilling during the first eight months of 1979 was 20.9 million feet, 20 percent less than at the same time in 1978. The total drilling for 1979 is expected to be about 40 million feet, far less than the 53 million feet planned by industry for the year. In contrast to less drilling in 1979, land acquisition appears to be on the increase as some companies take advantage of the lull by acquiring prospective targets.

Industry has indicated that use of U.S. Department of Energy's (DOE) National Uranium Resource Evaluation (NURE) data has helped to reduce their exploration lead times by supplying raw data useful in selecting targets. Also, the various compilations and topical studies of NURE have saved the industry considerable time and money by reducing the duplication of effort by individual companies. The widespread use of NURE data is indicated by the fact that approximately 800 copies of NURE reports are acquired each month through the Grand Junction Office library, and a substantial additional number of copies are acquired from other sources.

EXPLORATION TECHNIQUES

There have been no recent major breakthroughs in uranium exploration technology. The principal uranium exploration tool in use today remains the borehole geophysical log. The need for better information from a borehole has led to DOE's efforts in developing improved logging systems. Disequilibrium between the major gamma-emitting product (bismuth-214) and the parent uranium is a frequent source of error encountered in interpreting uranium content from conventional gamma-ray logs. DOE is supporting the development of direct uranium-logging systems, which induce and then measure emitted neutrons. The neutrons emitted from uranium are activated by bombardment with neutrons emitted from a source in the logging tool; two neutron sources are being investigated. Improved slim, high-yield neutron generators have been designed, and commercial prototypes will be available to the industry in 1980. A system utilizing californium-252 as a neutron source is being field tested, and an improved commercial system is now available on a limited basis.

As uranium exploration moves into deeper zones and into frontier areas, the application of sophisticated geochemical and geophysical techniques becomes more important. Methods of identifying halos of mineralization associated with uranium deposits are being investigated. Combinations of techniques being tested to optimize exploration include borehole logging measurements; applications of conventional geophysical techniques from the surface (high-resolution seismic, magnetic, electrical); measurements of radiogenic isotopes such as radon, helium, and lead-210; uranium isotopic ratios $^{238}U:^{234}U$ in the rocks and formation waters; and possibly hole-to-hole or hole-to-surface electrical measurements.

The application of remote sensing systems to uranium exploration appears to be gaining support each year. New types of multispectral data and computer enhancement of satellite images are proving useful.

DOE's calibration facilities for various kinds of gamma-ray measuring systems have been expanded for the benefit of both NURE and industry uses. Facilities include model boreholes at Grand Junction and at field locations to calibrate the increasingly sophisticated logging instruments. Currently, there are over 2,500 usages of model holes per year. New models are being constructed at the field sites to calibrate spectral gamma-ray and neutron logging systems. Five gamma-ray source pads located at Walker Field in Grand Junction and at the Dynamic Test Range near Lake Mead in Arizona are used for calibrating and controlling the quality of aerial survey systems.

FACTORS INFLUENCING CURRENT EXPLORATION

The uranium market, as measured by prices, has been in a stable condition since early 1977; however, if allowance is made for inflation, effective uranium prices have declined. The uncertainty of future demand and prices has tended to result in more conservative exploration plans. Production schedules and marketing arrangements for the large, high-grade deposits being developed in northern Saskatchewan and in Australia's Northern Territory represent another uncertainty in the domestic uranium market.

Safety and environmental concerns, dramatized by the Three Mile Island incident, have contributed to a reluctance on the part of some utility companies to continue supporting strong exploration programs. Several utilities have pulled out of exploration completely, and others have reduced their joint-venture funding; however, some continue to support active exploration programs.

Land withdrawals for wilderness studies, such as RARE II of the Forest Service and those administered by the Bureau of Land Management (BLM) under the Federal Land Policy and Management Act of 1976 (FLPMA), are reducing the availability of prospective target areas. RARE II is far from being completed and the BLM's massive wilderness inventory is barely underway. It will be many years before the final designation of these lands as wilderness or nonwilderness. Meanwhile, more than 100-million acres will remain largely inaccessible to exploration for minerals including uranium.

The uranium industry is being regimented with environmental and safety regulations at many levels of government, from county to federal. In addition, opponents of nuclear development are resorting more frequently to court actions to halt uranium activities. For example, a lawsuit to halt all uranium development in the Grants mineral belt was initiated during the past year; the suit recently was decided in favor of the industry. Such actions can add substantially to the cost and length of time required to carry out exploratory programs.

The soaring costs of deep mining in both New Mexico and Wyoming also have been a constraining influence on exploration plans, as evidenced by the fact that some planned deep drilling projects have been postponed or cancelled.

EXPLORATION HIGHLIGHTS

Uranium exploration in the United States continues to be concentrated in the vicinity of the major producing areas and in areas of past production, including the Wyoming Basins, Paradox Basin, Henry Mountains, southern San Juan Basin, south Texas Coastal Plain, the Black Hills, and northeast Washington. The distributions, by location, of total surface drilling for 1978 and the first half of 1979 are shown in figure 1. Of the 14.8 million feet reported for the first half of 1979, the Wyoming Basins (led by the Powder River Basin) account for 35 percent, San Juan Basin for 12 percent, Paradox Basin for 12 percent, and south Texas for 23 percent. Drilling in the High Plains, which includes the Black Hills, and in the Basin and Range, accounts for 5 and 3 percent, respectively. In these areas, explorationists using geologic models based on knowledge of the known deposits are discovering and developing additional reserves. Significant developments in both nonsandstone and sandstone areas of interest are summarized in the following sections. No new districts or major discoveries in new geologic environments have been reported during the past field season.

Nonsandstone Environments

Exploration in nonsandstone environments continues to increase and has reached a new high in 1978. Table 1 shows the number of companies and the expenditures involved in exploration of these environments. The number of companies reporting nonsandstone activities increased from 72 in 1977 to 90 in 1978, and the related expenditures increased from $34 million to $62 million during this period. In 1978, expenditures in nonsandstone environments amounted to 20 percent of the total exploration expenditures.

In Alaska, igneous and metamorphic environments are being explored in both the Seward Peninsula and on Prince of Wales Island (figure 2). The recently announced uranium discovery on Mt. Prindle, in the White Mountains of east-central Alaska, appears to be significant. This occurrence reportedly is similar to deposits in alkaline rocks of

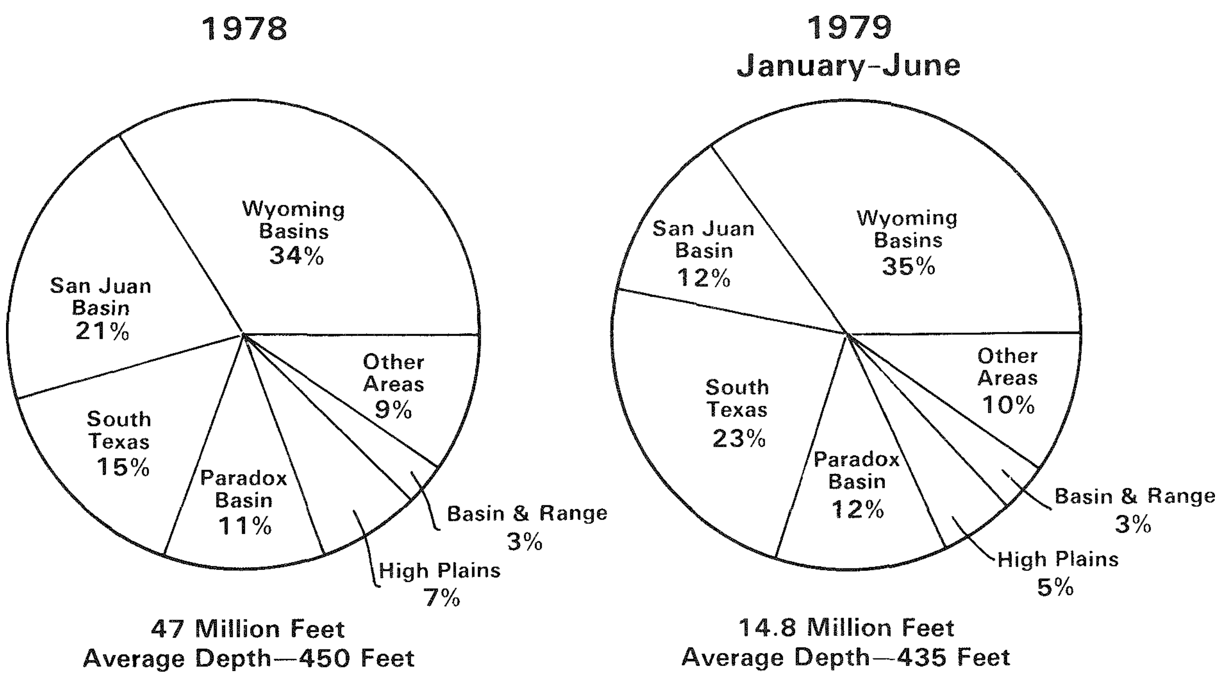


FIGURE 1. *Distribution of surface drilling by location*

TABLE 1. *Exploration in nonsandstone environments*

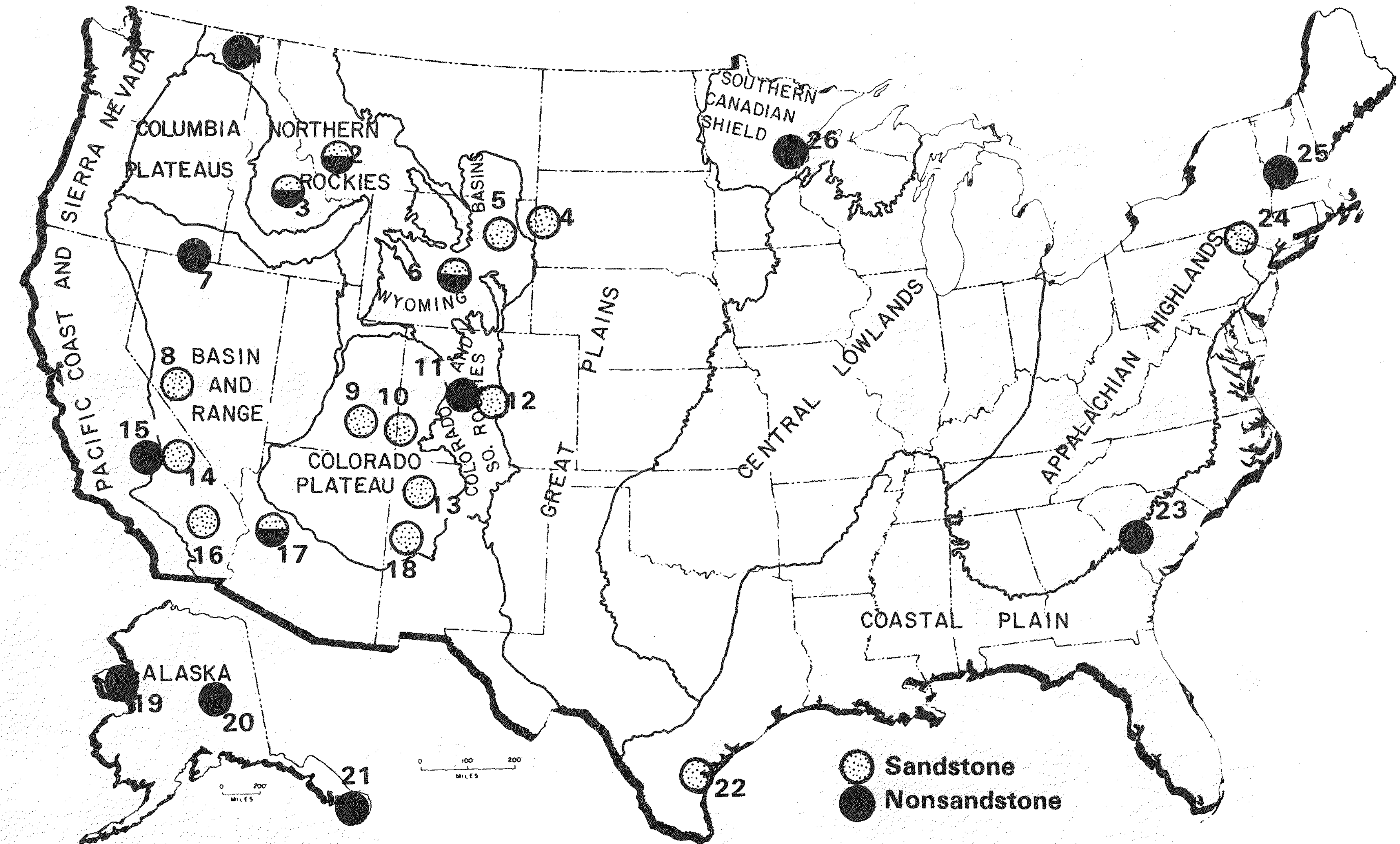
Year	Number of Companies	Millions of Dollars	Percent of Total Expenditures
1974	39	12.9	16.3
1975	39	13.6	11.3
1976	51	28.5	16.7
1977	72	33.8	13.1
1978	90	61.9	19.7
1979 planned	86	63.0	18.6
1980 planned	62	61.6	19.6

Pocos de Caldas, Brazil. Gneissic domes and the margins of plutons are being evaluated in northeastern Washington and elsewhere in the Rocky Mountains and in the Basin and Range.

In the Sierra Nevada, additional ore has been developed at the Miracle Mine in California's Kern River Canyon. The ore occurs in fractures in the Isabella Granodiorite of Cretaceous age. This activity has encouraged additional exploration in this area of the Sierra Nevada.

In December 1978, the discovery of a uranium deposit on the Oregon side of the McDermitt caldera in Nevada and Oregon was announced. This prompted a surge of exploration for uranium deposits in stratiform volcaniclastics and in veins in the McDermitt area and in other calderas in the Basin and Range. In Utah, a recent USGS open-file report on the Mount Belknap caldera, near Marysvale, indicated that the caldera-fill and ring-fracture zones are very favorable for uranium. Other volcanic and lacustrine environments are being explored elsewhere in the Basin and Range.

The announcement of a new mine and mill complex near Marshall Pass has focused attention on the Gunnison area of central Colorado. Vein-type deposits associated with fault breccias in rocks of various geologic ages are the exploration targets.



1. NE Washington
2. SW Montana
3. Central Idaho
4. Black Hills
5. Powder River Basin
6. Central Wyoming
7. McDermitt
8. East Walker River
9. Henry Mountains
10. Paradox Basin
11. Gunnison
12. Tallahassee Creek
13. San Juan Basin
14. Owens Valley
15. Kern River Canyon
16. Mojave Desert
17. W Central Arizona
18. E Mogollon Slope
19. Seward Peninsula
20. Mt Prindle
21. SE Alaska
22. South Texas
23. Aiken
24. Catskill Delta
25. Green Mountains
26. Eastern Minnesota

FIGURE 2. *Significant exploration activities, 1979*

Precambrian quartz-pebble conglomerates are receiving attention in the Rocky Mountains and in the Black Hills. As part of the NURE world-class studies, this geologic environment is being evaluated throughout the western United States.

Exploration is continuing in Precambrian rocks of the southern Canadian Shield of east-central Minnesota where previous DOE-sponsored studies identified geologic conditions resembling those of the unconformity-related uranium deposits in northern Saskatchewan.

One of the more active areas in the eastern United States is the Green Mountains in Vermont, where the crystalline rocks of the Precambrian Mt. Holley complex appear favorable for uranium occurrences. Known exploration activities in the Precambrian metamorphic rocks of the Grandfather Mountain area of North Carolina have ceased due to uncertain land availability.

Investigations by DOE's Savannah River Laboratory have disclosed numerous occurrences of uranium-bearing gorceixite in Aiken County, South Carolina. Gorceixite, a complex barium-phosphate mineral, is known to contain trace amounts of uranium in widespread occurrences elsewhere, but the Aiken County occurrences, containing 80 to 850 ppm U_3O_8, are the highest grade known. Investigations of the uranium resources associated with the South Carolina gorceixite deposits are continuing under the NURE hydrogeochemical program.

Sandstone Environments

Despite increasing attention to nonsandstone environments, exploration continues predominantly in the sandstone host rocks of the uranium-producing areas. During the first half of 1979, the Colorado Plateau, Wyoming Basins, and Texas Coastal Plain accounted for 88 percent of the total industry drilling reported to the Grand Junction Office. The Powder River Basin in Wyoming, which had 20 percent of the total 1978 domestic drilling, continues to lead all areas. In this basin, sandstones of Paleocene and Eocene age are the targets. Eocene sandstones in the Wind River, Shirley, and Great Divide Basins also are important exploration targets. Precambrian crystalline rocks and Paleozoic and Tertiary sedimentary rocks in central Wyoming, located in the vicinity of the south Granite Mountains fault zone, are receiving considerable attention.

Exploration has slowed in the San Juan Basin of northwestern New Mexico where drilling in the first half of 1979 represented only 12 percent of the total for the United States compared with 21 percent in 1978 (figure 1). During the latter part of 1978, a DOE geologic drilling project penetrated significant mineralization at depths in excess of 4,000 feet in the Chaco Canyon area which encouraged some additional drilling by industry in this general area. However, most drilling being done this year in the San Juan Basin is to depths of less than 2,000 feet. Litigation, lack of available land, market uncertainties, and the escalating costs of deep mining are having a restraining influence on deep drilling projects.

South of the San Juan Basin, in the East Mogollon Slope area of the Colorado Plateau, exploratory drilling is being conducted in the Baca Formation of Eocene age. This formation yielded 200 tons of ore from mining during the 1950s in the Red Basin and Hooks Ranch areas of New Mexico.

Northwest of the San Juan Basin, the Paradox Basin of southwestern Colorado and southeastern Utah is the site of intensive drilling for deposits in both the Morrison and Chinle Formations. The announcement of the discovery of a major ore body in the Chinle adjacent to the Velvet Mine in southern Lisbon Valley has spurred exploration for other Chinle targets. Exploration in the Salt Wash Member of the Morrison Formation in the Paradox Basin continued to be successful, both on the DOE lease blocks and in the La Sal, Utah, area.

In Utah's Henry Mountains, west of the Paradox Basin, aggressive exploration continues in the Salt Wash Member. Recently, Plateau Resources, Ltd., received license approval for a proposed mill at Ticaboo, Utah, where mine development is already in progress.

Exploration drilling has increased in the Tertiary basins of southwestern Montana in the search for Wyoming-type roll-front deposits. Some exploration is being directed toward nonsandstone deposits in adjacent ranges. In central Idaho, there has been some exploration in both sandstone and nonsandstone environments.

Exploration of sandstones of various geologic ages is being carried on in the High Plains of Montana, North Dakota, South Dakota, Wyoming, Colorado, New Mexico, and Texas. One of the most active areas is the Black Hills of South Dakota and

Wyoming where the target host rocks are sandstones in the Inyan Kara Group of Early Cretaceous age.

The discovery of large uranium deposits in the Tallahassee Creek area of Colorado, announced in 1977, continues to encourage exploration for other deposits in Tertiary channel fill in the central part of the State.

Drilling in the Texas Coastal Plain has increased over previous years but is not as widespread as before. Most of this year's drilling is restricted to the area from Fayette County southward to the Rio Grande where deeper targets applicable to solution-mining technology are being examined.

Industry continues exploration of the ore-bearing Coso Formation of Miocene-Pliocene age in the Owens Valley area of California at the western edge of the Basin and Range. Elsewhere in the Basin and Range, exploration for deposits in sandstone continues in the East Walker River area of Nevada and in the Mojave Desert of California. Sandstone and volcaniclastic environments are being investigated in intermontane basins of west-central Arizona. The development by industry of the large reserves adjacent to the Anderson Mine, in the Date Creek Basin of Arizona, has been responsible for increased exploration for similar deposits throughout the southern Basin and Range.

In the eastern United States, the Catskill delta area of Pennsylvania and New York is being explored for uranium-bearing sandstones in the Catskill Group of Devonian age. Also, exploration continues in the Triassic basins, especially in Virginia.

EXPLORATION EXPENDITURES AND RELATED STATISTICS

Each spring the Grand Junction Office conducts a survey, by individual company, of the uranium industry's exploration activities during the preceding year and plans for the next 2 years. The results of the latest survey were published in "Uranium Exploration Expenditures in 1978 and Plans for 1979–1980," GJO-103(79), which presents a compilation of data from 174 responding companies. The following information, regarding exploration costs and plans, is taken from this survey.

Table 2 is a summary of annual exploration expenditures for land acquisition, drilling, and other costs since 1972. The $314 million spent for exploration in 1978 is 18 percent greater than the $258 million reported in 1977. Of the 174 survey respondents, 141 indicated plans to spend a total of $339 million in 1979, 8 percent more than in 1978. Planning of 1980 activities by some firms was incomplete at the time of the survey, but 107 of the responding companies reported plans to spend $314 million in 1980. It should be noted that

TABLE 2. *Summary of domestic exploration expenditures*

	Millions of Dollars			
Year	Acquisition	Drilling	Other	Total
1966	2.24	2.60	3.55	8.39
1967	7.56	8.50	8.76	24.82
1968	18.52	21.35	13.58	53.45
1969	13.89	29.19	15.67	58.75
1970	10.74	25.17	16.29	52.20
1971	9.75	20.96	10.44	41.15
1972	4.70	18.10	9.60	32.40
1973	7.67	25.27	16.53	49.47
1974	12.61	44.76	21.71	79.08
1975	16.70	73.81	31.52	122.03
1976	13.89	108.97	47.79	170.65
1977	28.22	155.03	74.83	258.08
1978	30.73	169.68	113.85	314.26
1979 planned	—	—	—	338.90
1980 planned	—	—	—	314.30

the survey was conducted prior to Three Mile Island, and its effects, if any, will not show up until next year's survey.

Drilling is the single largest exploration expense and generally accounts for more than half of total exploration expenditures. The cost of acquiring land is a significant part of uranium exploration costs. For example in 1978, this cost represented 10 percent of the total exploration expenditures. The average acquisition cost per acre in 1978 was $4.81.

Other exploration costs, shown in table 2, include those for geologic and geophysical investigations and research, costs incurred by field personnel during exploration, and overhead and administrative charges specifically associated with supervising and supporting exploration activities. In 1978, these other costs represented 36 percent of the total reported exploration expenditures. The $114 million spent in 1978 represents a 52 percent increase over the $75 million spent in 1977. Environmental studies needed to plan and execute exploration programs are becoming more involved and costly. This function, combined with increased use of geochemical and geophysical surveys, accounts for most of the increase in other costs. Grass roots research programs being carried out by companies to systematically evaluate possible new uranium plays are included here also.

A survey of the publicly recorded land acquisitions in 14 western states during 1978 indicated that nearly 86 percent consisted of mining-claim locations on federal lands. Approximately 4 percent were state lands and 10 percent were fee lands. As noted in the public record, numerous mining claims were located during 1978 in both inactive uranium-mining areas and frontier areas.

Table 3 is a historical summary of surface drilling and associated expenditures for industry's exploration and development efforts for 1966 through 1978 and plans for 1979 and 1980. Total footage drilled in 1978, for which costs were reported, was about 5 percent greater than the footage drilled in 1977, while total drilling costs for 1978 were 9 percent greater than in 1977. The total footage drilled does not include drilling from underground workings or for solution-mining production. In addition to actual drilling, surface drilling costs include drill-road construction, site preparation, geologic and other technical support, sampling, drill-hole logging, and site restoration. Total drilling costs ranged from less than $1.25 to more than $30 per foot. The average cost was $3.53 per foot, a slight increase over the 1977 average.

According to the exploration survey, industry planned to drill 53 million feet in 1979 and 51.5 million feet in 1980. Figure 3 shows the amount of drilling done in each year, 1975 to 1978, and in the

TABLE 3 . *Summary of surface drilling expenditures*

Year	Exploration Drilling		Development Drilling		Total Surface Drilling	
	Millions of Feet*	Millions of Dollars	Millions of Feet*	Millions of Dollars	Millions of Feet*	Millions of Dollars
1966	0.93	1.36	1.50	1.24	2.43	2.60
1967	3.87	6.18	2.92	2.32	6.79	8.50
1968	12.87	18.53	3.73	2.82	16.60	21.35
1969	19.69	24.85	4.79	4.34	24.48	29.19
1970	16.91	21.69	3.41	3.49	20.32	25.18
1971	11.80	17.01	3.08	3.95	14.88	20.96
1972	11.95	15.40	3.08	2.70	15.03	18.10
1973	11.76	19.50	5.25	5.80	17.01	25.27
1974	14.72	34.95	6.84	9.81	21.56	44.76
1975	15.69	51.92	9.73	21.89	25.42	73.81
1976	20.36	70.70	14.44	38.30	34.80	109.00
1977	27.96	99.40	17.62	55.63	45.48	155.03
1978	28.95	113.30	19.15	56.40	48.10	169.68
1979 planned	33.90	—	19.10	—	53.00	—
1980 planned	32.60	—	18.90	—	51.50	—

*From 1966-1972, 15.2 million feet of exploration and development drilling were not reported separately and are not included above.

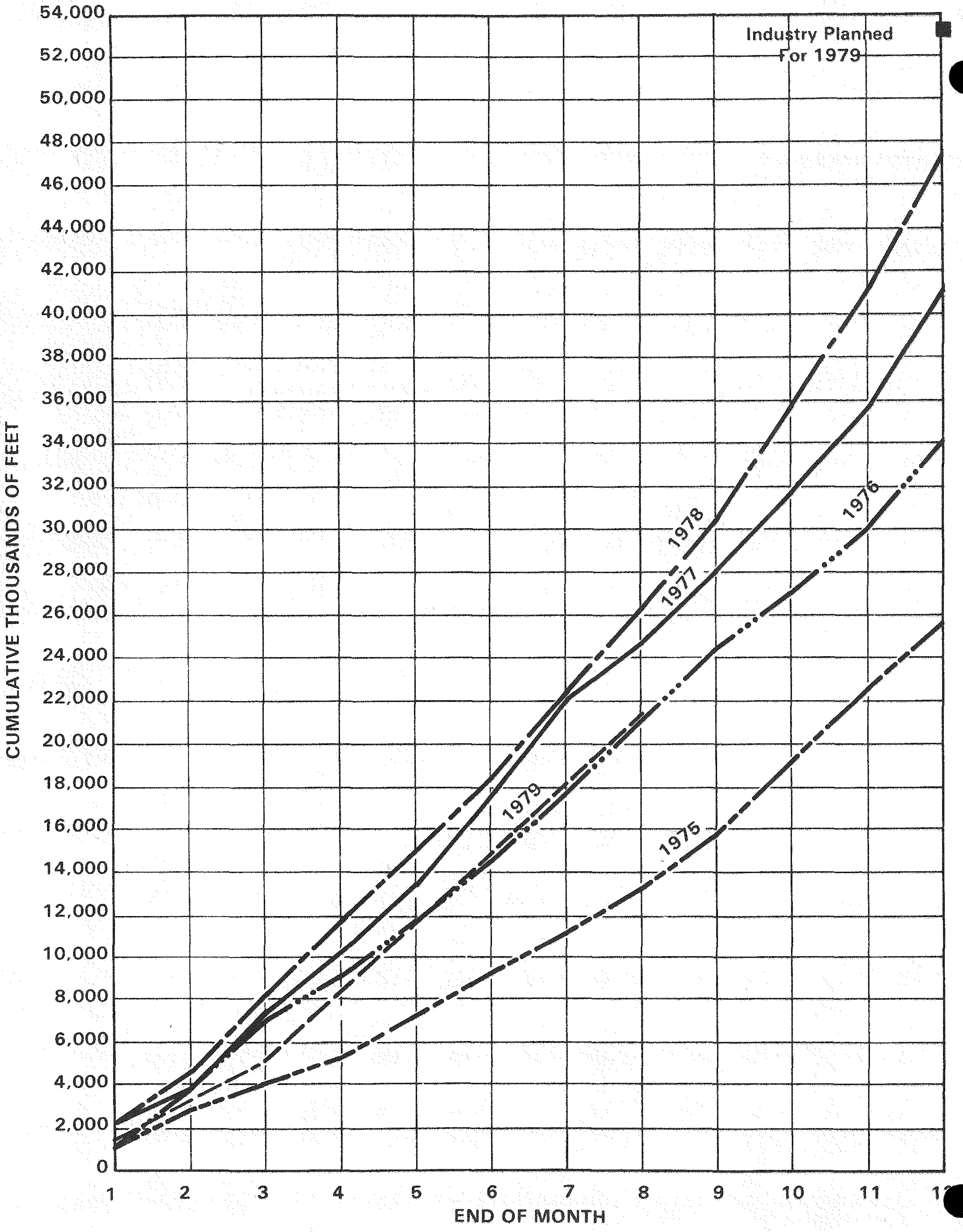


FIGURE 3. *Cumulative surface drilling as collected monthly comparing 1975, 1976, 1977, 1978 and 1979*

first 8 months of 1979. Based on current data, it appears that the total surface drilling for 1979 probably will not exceed 40 million feet, falling far short of the planned 53 million feet.

Exploration drilling, such as drilling in search of new ore deposits or extensions of known deposits, accounted for 69 percent of the total 1978 drilling effort. Development drilling, which defines the shape, size, and grade of deposits and provides information needed for mine planning, comprises the balance of the drilling. Drilling in 1978 was done with 375 rigs, and an estimated 370 logging trucks were utilized. This compares with 367 rigs and 332 logging trucks used in 1977.

Figures 4 and 5 show the regional distribution of exploration and development drilling, respectively, for the years 1969–1978. Exploration drilling in 1978 increased over 1977 in nearly all regions, with the exception of the San Juan Basin and central Wyoming. Development drilling in 1978 increased over 1977 in the San Juan Basin, Paradox Basin, Powder River Basin, and other areas, including the Black Hills, Rocky Mountains, and other portions of the Colorado Plateau as new properties were brought toward production. Areas showing decreases in development drilling from 1977 include south Texas and central Wyoming.

Figure 6 shows an analysis of the drilling by selected depth ranges for the years 1964 through 1978. The national average depth of holes drilled in 1978 was 450 feet compared with 434 feet in 1977. The depth increase apparently is due to increased drilling to deeper targets in New Mexico, Utah, and Texas during 1978. The national average for holes drilled during the first 6 months of 1979 was 435 feet (figure 1). During this period, the average depth of holes drilled in the San Juan Basin was 1,272 feet, whereas the average depth in the Wyoming Basins was 412 feet.

OUTLOOK FOR 1980

The uncertainties of the rate of growth of nuclear power and the uranium market, increasing world supplies, and rising production costs are expected to have an overall softening effect on uranium exploration in 1980. The pullback of some companies seen in 1979 is expected to continue into 1980. However, the current aggressive programs of other companies will no doubt carry over into next year. Surface drilling in 1980 probably will not exceed that of 1979. While exploration drilling may decrease, development drilling probably will continue at the same rate as in 1979 as more properties are brought toward production.

During the slowdown in exploration now being experienced, companies are becoming more selective in their exploration targets and are more imaginative in their application of geologic models, especially in nonsandstone environments. Although the drilling footage will be less than the all-time high in 1978, land acquisition might exceed that record year.

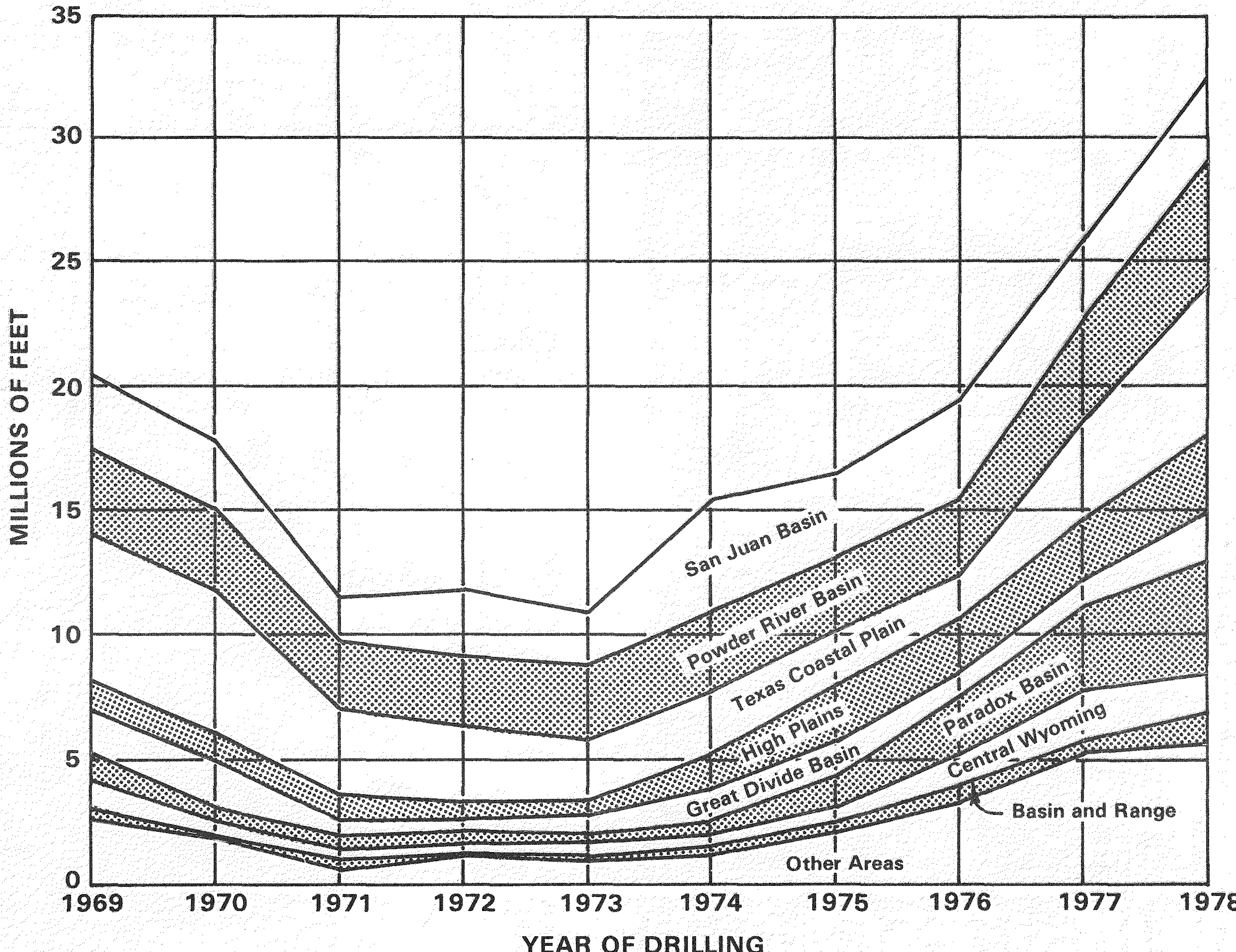


FIGURE 4. *Surface exploration drilling by area 1969 through 1978*

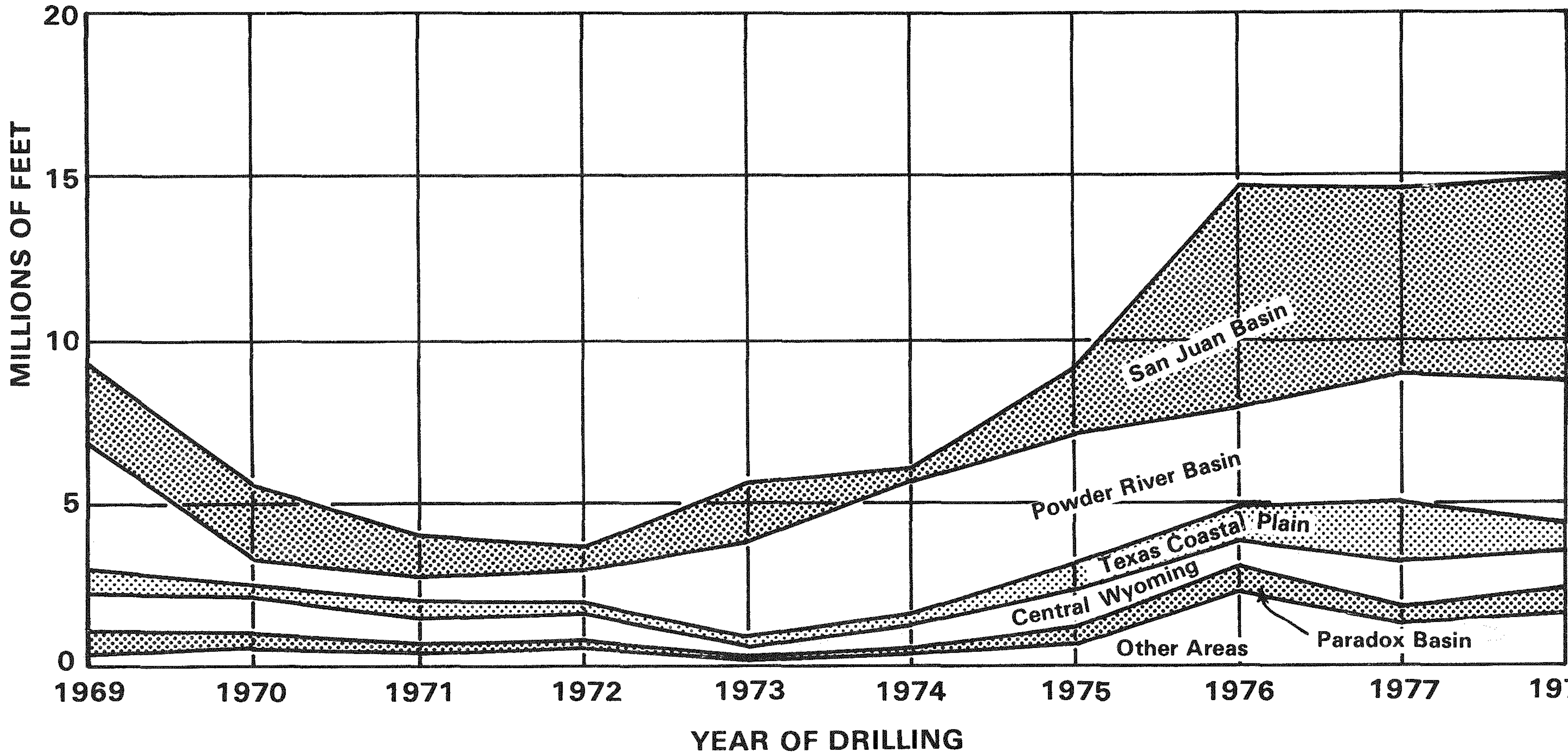


FIGURE 5. *Surface development drilling by areas 1969 through 1978*

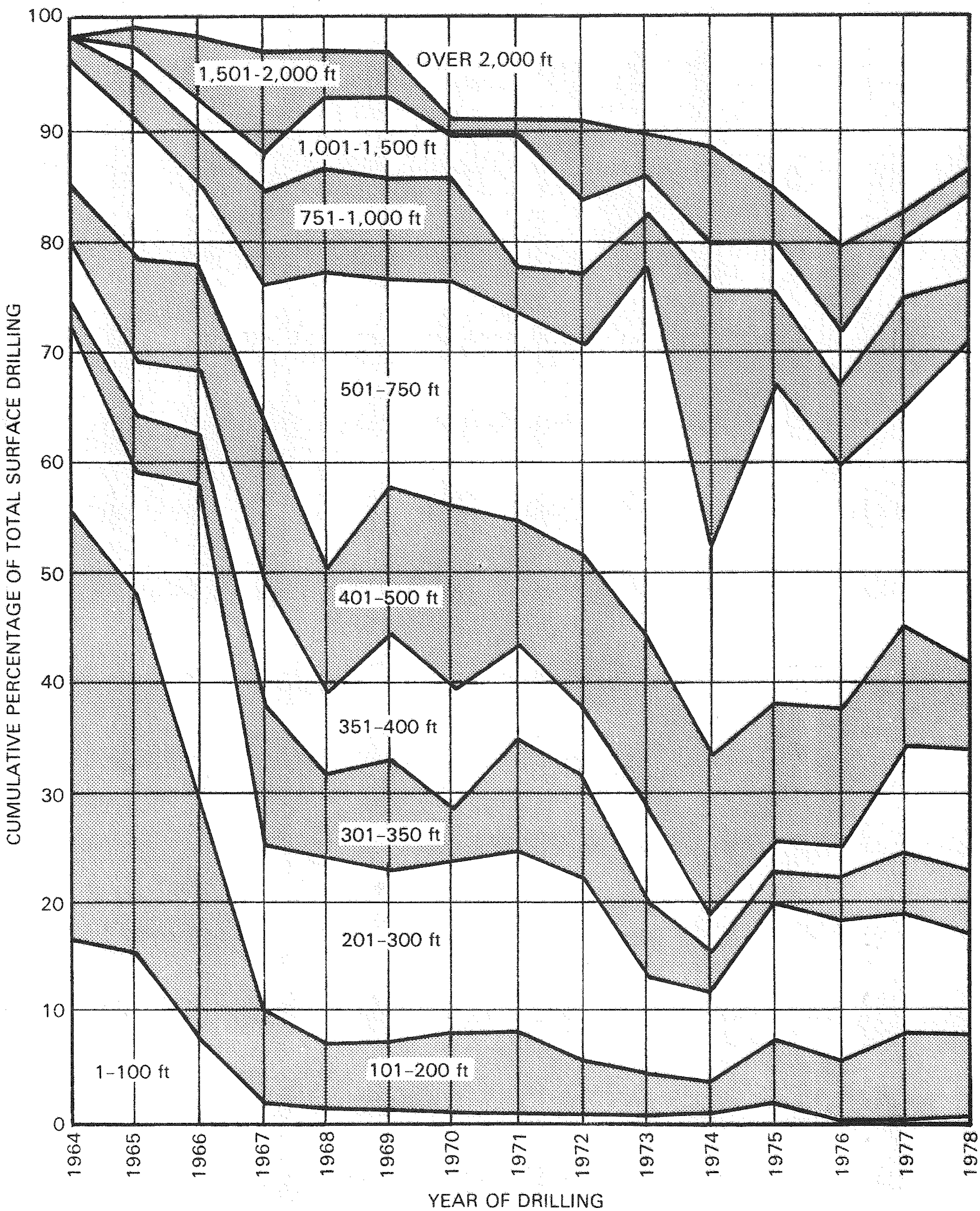


FIGURE 6. *Percentage of surface drilling by selected depth ranges 1964–1978*

RESULTS OF LOW-GRADE URANIUM STUDIES

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October 1979

INTRODUCTION

At this seminar last year, I reported that U.S. Department of Energy (DOE) studies were underway to reevaluate certain very large but low-grade types of uranium resources which have been known for many years. These resources are:

- Seawater,
- Phosphates, and
- Chattanooga Shale.

Now that these studies, or at least the initial phases, have been completed, we thought it might be of interest to summarize the results. Each of these studies was intended to determine the technical, economic, and environmental feasibility of recovering uranium either as a single product, a byproduct, or a coproduct, if other elements or constituents appeared to be of marketable value. The intent of this presentation is to summarize the studies and to give special attention to the estimated costs of production. Much of this information has been taken from the report summaries; for more detail, please refer to the individual reports cited in the reference section at the end of this report.

To put these low-grade uranium resources in perspective, table 1 shows the uranium concentration and the total estimated quantity of uranium for each resource studied.

Although these resources contain significant quantities of uranium, there are formidable problems that obviate any large scale production. The question then arises, "Why are such studies undertaken?" The justification stems from the concern about the adequacy of domestic uranium resources in conventional-type deposits. Since some of these low-grade resources are often referred to as the "fall-back" resources, these would have to be exploited if other domestic sources of uranium should become insufficient.

TABLE 1. *Low-grade uranium resources studied*

Resource	U_3O_8 Grade	U_3O_8 Content (tons)
Seawater	3-4 ppb	5×10^9
Phosphates	50-200 ppm	4×10^6
Chattanooga Shale	55-70 ppm	5×10^6

These resources have been studied in the past and perhaps will be studied again in the future, depending upon uranium demand and price, the success of future exploration efforts, and improvements in process technology.

SEAWATER

Table 1 shows that the Earth's oceans contain a tremendous quantity of uranium (five billion tons U_3O_8). For this reason, the possibility of recovering uranium from seawater, which averages only 3 to 4 ppb U_3O_8 has intrigued various investigators for many years, especially researchers in countries without any other significant uranium resources. To examine the feasibility of uranium recovery from seawater in this country, a contract was awarded in 1978 to EXXON Nuclear Company, Inc. (ENC), Richland, Washington. The overall objective for the study was to determine the resource base and the technical, economic, and environmental feasibility of large-scale recovery of uranium, as a coproduct and as a single product, from seawater off the coasts of the United States. A multidisciplinary work group was assembled under project managment of ENC to fulfill this broad objective. Oregon State University provided technical expertise from its nuclear engineering, oceanography, chemistry, and chemical engineering departments. Vitro Engineering Corporation developed engineering flowsheets and provided architectural engineering design.

The scope of ENC's study was limited to the oceans adjacent to the continental United States, its possessions, and its trust territories. ENC considered such parameters as: uranium concentrations, current flow, temperature, turbidity, and others, that may affect availability, recoverability, and deliverability of uranium to an extraction plant. Delivery schemes utilizing (1) ocean current flow, (2) tidal flow, and (3) pumped-flow were considered in site selection for a conceptual plant design effort.

Although ocean current flow delivery is being considered by Japanese and German investigators, the configuration of adsorber beds is still within the developmental stage, and the concept, in the opinion of ENC investigators, is not yet sufficiently defined for conceptual design and cost estimation. Hence, this delivery scheme was not considered further by ENC.

A possible location identified by ENC for a tidal flow plant is Cook Inlet which is located along the Alaskan coastline and borders on the Gulf of Alaska. High tides, generally greater than 5 meters and sometimes as high as 10 meters, are found in Cook Inlet. The year-round temperature range of the water, from 4° to 11° C, offers poor uranium adsorption kinetics, while the biological productivity creates an adsorber-fouling problem. These unfavorable conditions, as well as a lack of fresh water, make Cook Inlet unattractive as a site for a tidal flow plant.

ENC concluded that pumped-flow delivery requires siting at a location with optimum uranium recovery conditions, which include:

1. High salinity (which also indicates best uranium concentrations),
2. Assurance of seawater feed nondepleted in uranium, by having an optimum current regime,
3. Seawater temperature in the 26° to 30° C range to assure high extraction efficiency,
4. Low water clarification requirements,
5. Near sea level elevation for the plant with a *minimum of offshore-onshore slope, and*
6. A large volume and supply of fresh water.

One such site, in southeastern Puerto Rico, appeared to meet these criteria for a pumped-flow delivery system. The Puerto Rico site was used for preliminary conceptual design and cost estimating purposes.

ENC proposed using the same process developed by the researchers in England in the 1960s, namely the adsorption of uranium on beds of hydrous titanium oxide. The uranium-loaded beds require washing with fresh water prior to elution with an ammonium carbonate solution and then a postwash with additional fresh water. The uranium-bearing solution is heated with steam to remove ammonia and carbon dioxide, which are recycled, and to precipitate the uranium, which is filtered and dried.

The ENC study concluded that it would be technically feasible to recover uranium from seawater off the coast of Puerto Rico although a number of site-specific studies should be conducted prior to final site selection. It is not feasible from an engineering viewpoint to go beyond the preliminary conceptual design for a pumped-flow system without conducting further studies. It would be socially feasible to recover uranium from seawater as long as the plant site was in a low-population area. The environmental impacts appear to be amenable to mitigation by current technology. Without major technical break-throughs, such as increased adsorber capacity and decreased chemical and fresh water requirements, which would lead to significantly lower production costs, a pumped-seawater plant to extract uranium from seawater is not economically feasible. ENC concluded that if a plant were built by 1995, the cost of extracting uranium from seawater would range from \$2,100 to \$2,600 per pound U_3O_8. The production cost is extremely capital intensive, and as such, the projected costs are sensitive to the method of financing the project. A private venture, without government support, could not produce uranium for under \$2,700 per pound, and the most probable commercial cost would be about \$3,600 per pound U_3O_8. ENC's most optimistic, hypothetical case (\$600 per pound U_3O_8 in 1990) assumes major technical breakthroughs, most favorable economic climate, and financing on strictly a cost recovery basis with no allowance for risk or contractor fees.

The above costs were based on a pumped-flow system plant capable of producing 550 tons U_3O_8 per year from seawater averaging 3 to 4 ppb U_3O_8

at an overall recovery of about 70 percent. The plant capital cost (1978 dollars) was estimated at $6.2 billion and would require 15 years to design, engineer, and construct, with plant start-up in 1995.

PHOSPHATES

The objectives of this study were to determine (1) the technical, economic, and environmental feasibility of uranium recovery from various uraniferous phosphate resources in the United States and the Free World, and (2) the quantities of uranium that might be recovered through the year 2025 from those resources as either a byproduct, coproduct, or single product. The study was undertaken in July 1978 by Earth Sciences, Inc. (ESI), Golden, Colorado, and was completed with the recent issuance of the final report.

ESI concluded that uranium availability from phosphate resources during the next 50 years will be almost entirely dependent upon the production of wet-process phosphoric acid—an intermediate step in manufacturing phosphate fertilizers. No other phosphate resource was considered to be a viable source of uranium during the next several decades because no process has been found that will selectively extract uranium. Hence, special emphasis was given to byproduct recovery of uranium from wet-process phosphoric acid.

The current wet-process phosphoric acid production capacity of the Free World is 24.3 million tons P_2O_5 per year, of which 40 percent is in the United States. Such acid production is estimated to contain approximately 9,200 tons U_3O_8 annually of which 4,250 tons would be in acid produced in the United States. ESI reported average U_3O_8 concentrations in phosphoric acid ranging from a low of 10 milligrams per liter (mg/l) in South Africa and Australia to 190 mg/l in acid produced in the United States from Central Florida phosphate rock. Assuming, that during the processing of phosphoric acid, 15 mg/l of U_3O_8 remain in the acid, ESI calculated the quantity of recoverable uranium at each plant based on U.S. economic conditions at a selling price of $40 per pound U_3O_8.

The cost of recovering uranium from phosphoric acid is a function of such items as the phosphoric acid plant capacity, the uranium content of the incoming acid, the uranium content of the acid returned to the phosphoric acid plant, the type of acid ("green," "black," "hemihydrate," etc.), the location, and the degree of integration with the fertilizer production complex. ESI estimated that a uranium extraction facility to treat acid from a plant with an annual capacity of 50,000 tons P_2O_5 would cost about $5 million, while a facility to treat acid containing 300,000 tons P_2O_5 would cost $18 million. However, the smaller plant would require a price of $60 to $70 per pound U_3O_8 to realize an adequate return on investment. In general, most wet-process phosphoric acid plants in the United States with an annual capacity of 150,000 tons P_2O_5 and a U_3O_8 concentration of 140 mg/l could produce uranium profitably at a selling price of $40 per pound of U_3O_8.

Utilizing their estimated capital and operating costs, ESI reported that 88 percent of the uranium contained in phosphoric acid in the United States is recoverable for a selling price of $40 or less per pound U_3O_8. On this basis,the larger phosphoric acid plants in this country could produce an estimated 3,750 tons U_3O_8, if all plants operated at capacity.

A similar analysis of phosphoric acid plants outside the United States revealed that only 42 percent of the total uranium would be recoverable at $40 or less per pound U_3O_8 because of the preponderance of small phosphoric acid plants or the low uranium content of the acid. Throughout the Free World (excluding the United States), an estimated 5,820 tons U_3O_8 currently appear to be recoverable at $40 or less per pound.

From their 1978 uranium production capability estimates, ESI made projections of phosphoric acid plant capacities, sources of phosphate rock, and estimated byproduct uranium recoverable in the year 1985. Projections were then made for the 1985–2000 period and finally to the year 2025. It was estimated that byproduct uranium recovery could amount to 4,400 tons U_3O_8 per year by 1980 for U.S. plants. The annual uranium recovery could increase to about 6,000 tons U_3O_8 in 1985 and then decrease gradually to about 5,000 tons in 2000 and 4,600 tons in 2025. Cumulative byproduct uranium production in the United States could amount to 113,000 tons U_3O_8 through 2000 and 232,000 tons U_3O_8 through 2025.

Byproduct uranium recovery from phosphoric acid plants throughout the remainder of the Free World could amount to 2,500 tons U_3O_8 in 1980, increasing to an annual rate of 3,700 tons in 1985, 7,500 tons in 2000, and 16,000 tons of U_3O_8 in

2025. Cumulative Free World production could total about 105,000 tons U_3O_8 through 2000 and an estimted 400,000 tons U_3O_8 through 2025. Byproduct uranium production is projected by ESI to decrease in the United States as the higher uranium-grade Central Florida phosphate rock is depleted. Phosphoric acid production capacity is projected to remain relatively constant after 1985, but the uranium content will decrease as lower uranium-grade rock is used to make acid. Conversely, ESI projects substantial increases in phosphoric acid plant capacities for other countries of the Free World, expanding about fourfold from 1985 to 2025.

ESI also compiled information and data on the uraniferous phosphate resources of the United States and of the Free World, giving special attention to the uranium content of reserves and potential resources of marine phosphorites of the southeastern United States and of the Western Phosphate Field. Phosphatic materials, other than phosphate rock, were evaluated as possible future sources of uranium. These included igneous apatite deposits, monazite placer deposits, phosphatic shales, Florida leached zone, Florida phosphate slimes, unbeneficiated ore-grade phosphate resources, vanadiferous shales of the Western Phosphate Field, phosphate fertilizer intermediates, and electric-furnace phosphate slag. None of these resources is considered a viable source of uranium under current economic conditions utilizing presently known processing technology. Since the estimated costs for producing significant quantities of uranium directly from these phosphate resources, either as a single product or as a coproduct, are so high, about $200 per pound U_3O_8, there is no incentive for further study of these resources at this time.

CHATTANOOGA SHALE

At this seminar last year, the results of the DOE-approved uraniferous shale study were summarized briefly. I should like to take this opportunity to review that study and present more details, especially on estimated costs of production, and suggestions for follow-up studies.

The Chattanooga Shale of Late Devonian age extends, with fairly uniform thickness and lithology, over large areas of the east-central United States. It contains large amounts of uranium and has been investigated intermittently since 1944. Although the uranium content is quite low, averaging about 60–65 ppm U_3O_8, Chattanooga Shale is estimated to contain about 5 million tons U_3O_8.

The Chattanooga Shale study was conducted by Mountain States Mineral Enterprises, Inc., Tucson, Arizona. The assessment of environmental and socioeconomic impacts was performed by PRC Toups Corporation, Orange, California, and the shale mining plan and estimates of mine capital and operating costs were prepared by Cleveland-Cliffs Iron Company. The Institute of Gas Technology (IGT) at Chicago, Illinois, contributed information and data on its oil shale hydrogen retorting process.

The areal extent of Chattanooga Shale is known to encompass about 35,000 square miles in south-central Kentucky, central Tennessee, northeastern Alabama, and northwestern Georgia. Because of the relative abundance of geologic, analytical, and engineering data, the Youngs Bend area of DeKalb County, Tennessee, was selected by Mountain States as "typical" for assessment of the feasibility of mining and processing Chattanooga Shale for uranium recovery. Mountain States concluded that the exploitation of Chattanooga Shale, if at all possible, will have to be based upon mining and processing large tonnages with maximum efficiency in order to produce uranium at minimum cost. A plant throughput of 100,000 tons of shale per day was chosen as necessary and possible on a reliable daily basis with present-day equipment and technology.

Open-pit mining methods were considered but rejected because the ratio of overburden thickness to shale thickness is too great. Underground mining appears feasible, but three mines, each producing 36,000 tons per day, would be required. Cleveland-Cliffs estimated an average mine extraction of about 60 percent of the in-place shale and operating and maintenance costs for mining and backfilling with coarse tailings of about $2.80 per ton of shale mined.

Mountain States recommended processing the shale to recover a variety of products consisting of uranium, synthetic crude oil (syncrude), ammonia, and sulfur. Excess waste heat is used to generate electricity for sale. In addition, vanadium, cobalt, nickel, molybdenum, thorium and perhaps other metals could be recovered if recovery costs and market conditions were favorable.

The proposed use of the shale oil recovery technology developed by IGT is of special interest because of the potential for much higher syncrude yields than previously were considered possible from Chattanooga Shale. For example, shale with a Fischer Assay of only 8.7 gallons of oil per ton of shale could produce as much as 21.7 gallons per ton using the IGT process. All heat and power for the hydroretorting process is developed internally from the carbon in the shale. Retorted shale, still containing about half its original sulfur and some residual carbon, is then roasted. The roaster gas is cleaned and used to make sulfuric acid for uranium leaching. Roasted residues amounting to 80,000 tons per day are ground to 48-mesh, then leached with sulfuric acid. About 60 percent of the uranium in the roasted residues is dissolved with an acid consumption of about 200 pounds per ton of residues. Conventional uranium recovery processing follows, i.e. liquid-solid separation, solvent extraction, etc.

The leached residues or tailings are neutralized with lime and classified to remove the coarse fraction, about 70 percent by weight, which is used for mine fill. The fines, however, are pumped to surface storage, and their impoundment could constitute one of the most serious environmental problems.

A plant treating 100,000 tons per day of Chattanooga Shale at 65 ppm U_3O_8 would have an estimated annual production of 1,360 tons U_3O_8, 19.3 million barrels of syncrude, 171,500 tons of ammonia, and 790,000 tons of sulfur and have surplus electricity to sell. The other metals previously mentioned could be recovered by installing additional process facilities. Mountain States considered various shale processing schemes and performed detailed economic analyses to determine the uranium price required to produce varying rates of return on investment (ROI). The Mountain States mine economic analyses of mining and processing Chattanooga Shale, containing 65 ppm U_3O_8, are summarized in table 2. Table 2 shows the U_3O_8 prices required to generate a 15- and 20-percent return on investment (ROI), assuming, when syncrude is produced, prices of either \$14 or \$20 per barrel.

Also considered in the economic evaluation were various other possibilities with these results:

1. **Shale with a U_3O_8 content greater and less than 65 ppm**

   A higher grade shale, if it were available in sufficient tonnage, would improve the economics of uranium recovery. As shown in table 3 the price required to generate a given ROI decreases significantly if shale contains 100 rather than 65 ppm U_3O_8. Conversely, if shale contained only about 45 ppm U_3O_8, the Case III price at 20-percent ROI increases from \$230 to \$281 per pound.

2. **Improved recovery of uranium**

   Although Mountain States considers a 60-percent U_3O_8 recovery to be the most realistic, the effect of improved recovery was evaluated. In Case III (table 3) if recovery from 65 ppm U_3O_8 shale could be improved to 80 percent, the U_3O_8 price at 20-percent ROI would decrease from \$230 to \$173 per pound.

TABLE 2. *U_3O_8 price (\$/lb) required to generate 15% and 20% ROI*

	15% ROI		20% ROI		15% ROI	20% ROI
	\$14/bbl	\$20/bbl	\$14/bbl	\$20/bbl	No Oil	No Oil
Case I	112	70	188	147		
Case II	173	131	241	199		
Case III					206	230
Case IV					145	177

Case I – Recovering uranium, syncrude and byproduct metals
Case II – Recovering uranium and syncrude
Case III – Recovering uranium only
Case IV – Recovering uranium and byproduct metals

TABLE 3. *U_3O_8 price ($/lb) required to generate 15% and 20% ROI at various shale grades*

Shale Grade (ppm U_3O_8)	45		65		100	
ROI(%)	15	20	15	20	15	20
Case I*	–	–	70	147	45	95
Case II*	–	–	131	199	85	–
Case III*	–	281	206	230	133	149
Case IV	–	–	145	177	–	–

*Based on syncrude price of $20/bbl

3. ROI at 1978 U_3O_8 market price

Assuming U_3O_8 sales at the 1978 spot market price of $42.50 per pound and syncrude at $14 and $20 per barrel, the ROI for Cases I and II would be as shown in table 4. This analysis is based on shale containing 65 ppm U_3O_8 and 60-percent recovery. Case I shows the better ROI, but there are perhaps greater uncertainties because of added problems of recovering and marketing several metals, other than uranium, found in Chattanooga Shale. However, this analysis shows that in mining and processing shale containing 65 ppm U_3O_8 at a rate of 100,000 tons per day, and if all the byproducts were made and sold, one might realize an 8.9-percent ROI at a U_3O_8 price of $42.50 per pound and a syncrude price of $14 per barrel. The estimated capital cost would be $2.3 billion, and the direct annual operating cost would be $416 million.

The environmental and socioeconomic impacts of a Chattanooga Shale operation were assessed only in a general fashion, inasmuch as specific mine and plant sites had not been selected. Some environmental costs, such as tailings disposal and water treatment, were included in the economic analyses. Potential environmental and socioeconomic constraints were identified but not quantified for the economic analyses. The preliminary analysis indicated that a Chattanooga Shale project could be environmentally accommodated through proper site selection and careful planning.

TABLE 4. *ROI (%) at 1978 U_3O_8 market price*

	$14/bbl	$20/bbl
Case I	8.9	12.8
Case II	-0.9	5.6

As a final phase of the Chattanooga Shale study, Mountain States was requested to identify immediate, short- and long-range programs, and/or strategies for the development and exploitation of the resource. Utilizing the individuals and firms that participated in the initial study, Mountain States suggested 1½-, 5-, and 20-year development program plans for the guidance of DOE. The primary objective was to identify critical areas for future study and the problems that must be solved within the three time frames. The following items were thus identified:

1. Geology—Further exploration and drilling are required to define better the uranium and oil content and distribution.

2. Mining—An environmentally acceptable method of mining and waste disposal needs to be developed and proved.

3. Hydroretorting—The technical feasibility of oil extraction using this technique must be demonstrated in pilot and commercial size operations.

4. Uranium and Byproduct Recovery—Laboratory and pilot-plant metallurgical studies are required to develop commercially acceptable processes and flowsheets.

5. Environmental Feasibility—Possible environmental degradation from large-scale exploitation needs to be more thoroughly assessed for a site-specific location.

The estimated costs of the proposed "Development Program Plans" were $1.1, $5.6, and $4,804 million for the 1½-, 5- and 20-year time frames. The 5-year plan envisions pilot operations; whereas the 20-year plan includes demonstration of commercial size operations. The Grand Junction Office (GJO) has no current plans to undertake further studies of Chattanooga Shale as a source of uranium. The recovery of syncrude through hydroretorting of eastern shales is expected by the DOE fossil-fuel program.

RED MUDS

Red mud is the solid waste which remains after alumina has been caustic leached (using the Bayer process) from bauxite for the production of aluminum metal. Red mud is accumulating in this country at a rate of about 10 million tons per year, and some red muds may contain enough uranium to be of interest as a possible resource. In order to answer questions often raised about this potential resource, it was decided to sponsor a study to obtain definitive data. Accordingly, Bendix Field Engineering Corporation entered into a subcontract with Zellars-Williams, Inc.(ZWI), Lakeland, Florida, late in 1978 with these objectives:

1. To determine the volume, geographic distribution, average grade, and mineralogical state of the uranium, and

2. To correlate the red muds based on bauxite origin, wherever possible.

ZWI was to inventory, measure, sample, and analyze (for uranium and thorium) the red mud waste piles as well as current plant production. Because of analytical difficulties, ZWI has not yet completed the study.

CONCLUSION

DOE-sponsored studies have been completed on three low-grade resources: seawater, phosphates, and Chattanooga Shale. A study of uranium associated with the red muds is nearing completion. Each of the completed studies presents a current assessment of the technical, economic, and environmental feasibility of uranium recovery. Although none of these resources, except byproduct uranium from phosphates, is expected to contribute to the uranium supply in the foreseeable future, the studies do contain definitive and timely information and data that will be useful for long-range planning and future reference.

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These reports are available from the organization that performed the study or on microfiche from: Bendix Field Engineering Corporation, Technical Library, P.O. Box 1569, Grand Junction, CO 81502.

URANIUM PRODUCTION

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October 1979

INTRODUCTION

Domestic uranium production will be higher in 1979 than during any prior year, and much of the increase from the 1978 production level will come from nonconventional production. Uranium ore production is at a record level, but the ore grade is 15 percent lower than it was last year. Fortunately, mill recoveries have increased in spite of the drop in millfeed grade.

Two new mills began processing uranium ore and several small in situ leaching operations came on stream. Early this fall, uranium recovery will begin at another copper-leach operation and at another wet-process phosphoric acid plant.

Production was interrupted or delayed at several mills by strikes or concerns over possible environmental problems.

MINING (See figure 1)

Open Pit (See figure 2)

The 60 open-pit uranium mines are producing slightly more than half of the uranium in ore in the United States. The grade of ore being mined from individual open pits ranges from 0.03 to 0.25 percent U_3O_8 with an average of 0.09 to 0.10 percent U_3O_8. Wyoming continues to lead the nation in open-pit operations. All of the uranium ore being mined in Texas and Washington comes from open pits.

The largest uranium open pits produce up to 5,000 tons of ore per operating day (TPOD), but the average is about 700 TPOD or 160 tons U_3O_8 per year per pit. Today's average open pit is producing twice as much uranium ore as did the average pit of 1969, and there are about twice as many open pits operating now. Eight of them produced more than 1,000 TPOD last year, and perhaps a dozen will produce at that rate during 1979. Most open-pit mining continues to be done at depths of less than 400 feet because uranium ore deposits in sandstone tend to be too small for economic open-pit mining at greater depths.

Since 1970, there has been only one year, 1977, when the uranium contained in ore mined from open pits was less than that from underground mines. In each year prior to 1971, most of the uranium in ore came from underground mines. We had anticipated that this would again be true after 1976, because of the depth of lower cost reserves, but the trend to produce more ore from shallow rather than from deep orebodies has continued. Major factors in this trend have been the long lead-times and high costs required to develop deep underground mines. Uranium production from underground mines, however, may be expected to exceed that from open pits within the next 3 years.

Miner productivity increased slightly in both 1978 and 1979, but the present level of about 20 tons of ore per man shift from open pits is still about 30 percent lower than the productivity in 1973 and 1974. Much of the lower productivity may be attributed to the increasing number of state and federal regulations concerning mining, but high turnover of mine labor and the proportion of inexperienced workers are very significant factors.

Underground (See figure 3)

About 300 underground uranium mines will produce ore in 1979 although perhaps half that number will deliver ore during any calendar quarter because some mines only produce for annual assessment work, and some mines alternate between ore production and mine development work. This compares with the 1955 through 1961 boom years when more than 500 mines, most of which were underground and small, delivered ore during each calendar quarter. Most of today's underground mines are larger although more than a third of them each produced less than 1,000 pounds U_3O_8 in ore in 1978. Half a dozen under-

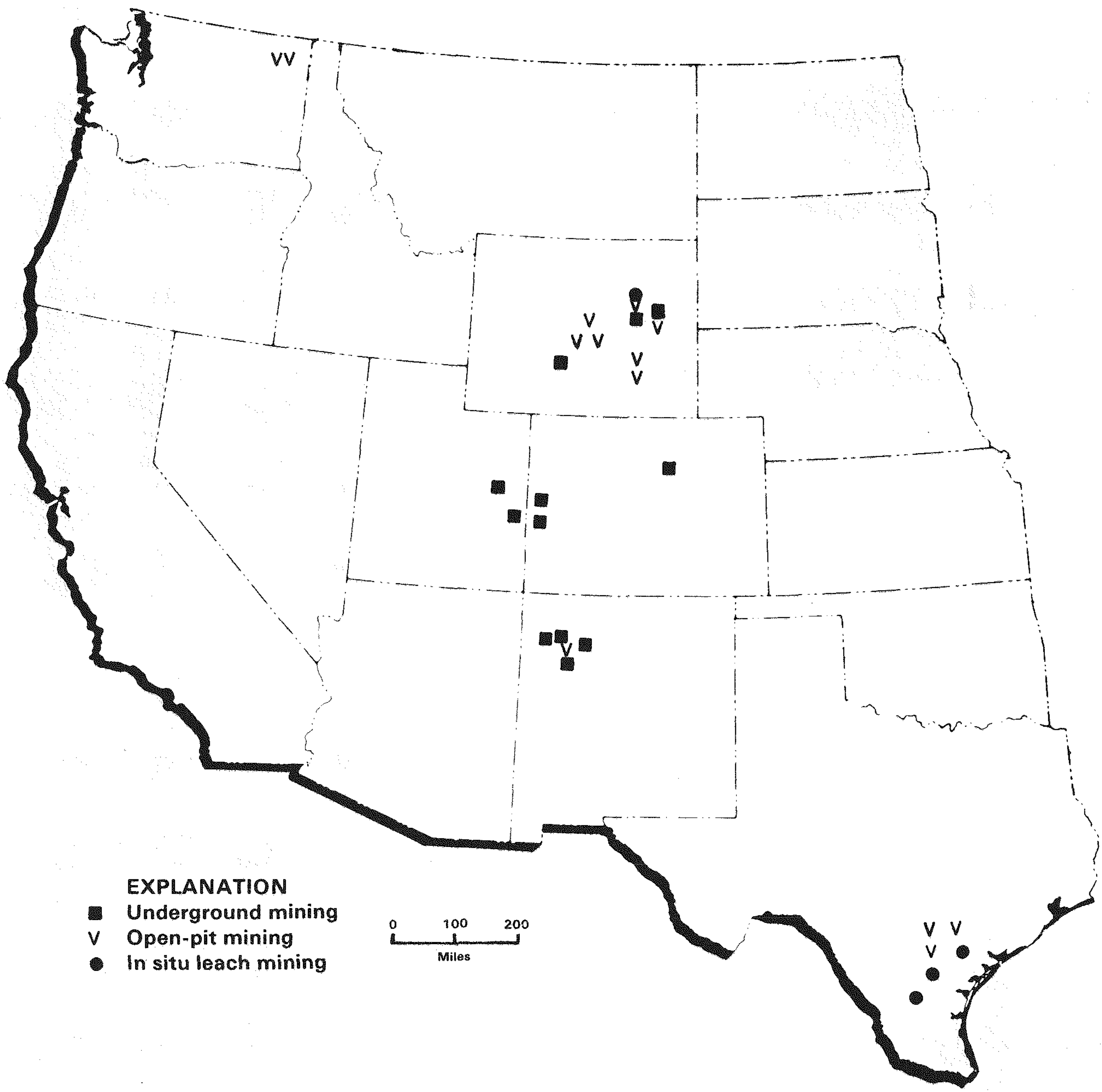

FIGURE 1. *Locations of major uranium mines in the United States*

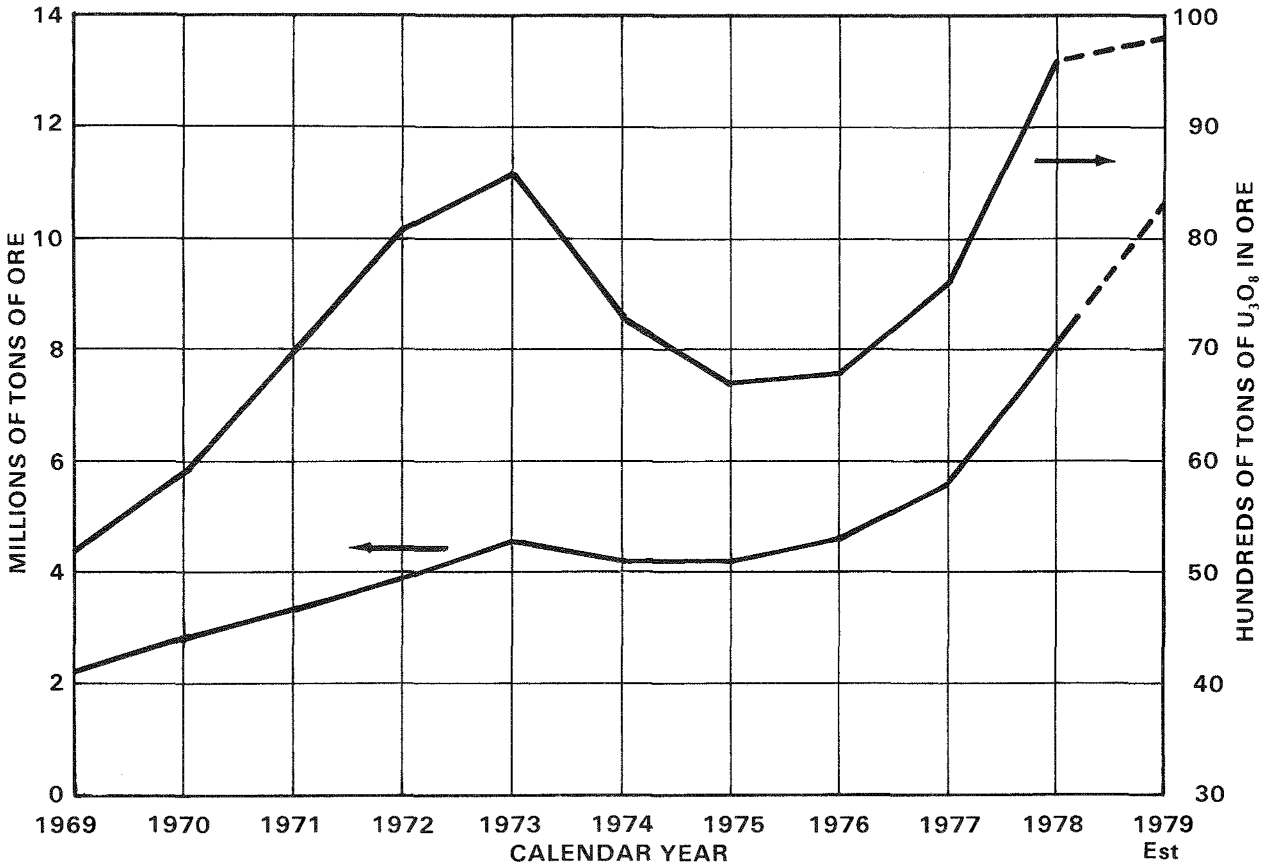

FIGURE 2. *Ore delivered from open-pit uranium mines*

ground uranium mines produced more than 1,000 TPOD in 1978. The largest mines are producing 2,000 to 3,000 TPOD, but the average for all mines is about 90 TPOD. Both underground and open-pit uranium mines normally operate 250 days per year.

Most of the uranium in ore produced from underground mines continues to come from depths of less than 400 feet, although the deepest mines have depths approaching 3,000 feet. The operating mines are located mainly in New Mexico, Colorado, and Utah, but underground mine production continues to increase in Wyoming.

The average grade of ore being produced from underground mines is about 0.14 percent U_3O_8 with values for individual mines ranging from 0.05 to more than 0.50 percent.

Miner productivity is nearing the 8 tons per manshift which was common at the beginning of this decade. Unfortunately, more service and support is needed now than earlier, so the productivity of total labor for underground uranium mining is 25 to 30 percent lower than it was 5 years ago. As in open-pit mining, the increased labor is necessary to comply with recent environmental and safety regulations.

Underground mines are producing almost 40 percent of the above-noted tons of uranium ore; because of the higher grade of ore produced from underground mines and the better mill recoveries for this higher grade ore, almost half of the uranium in concentrate produced from conventional ore comes from underground ore.

Solution (In Situ Leaching)

There are about 15 solution uranium mines in operation. A few of these are small test programs, but each of the others is producing more than 100,000 pounds U_3O_8 per year. Total U_3O_8 production from solution mines was about 100 tons in 1976, 500 tons in 1977, 1,000 tons in 1978, and is expected to be 1,500 tons in 1979.

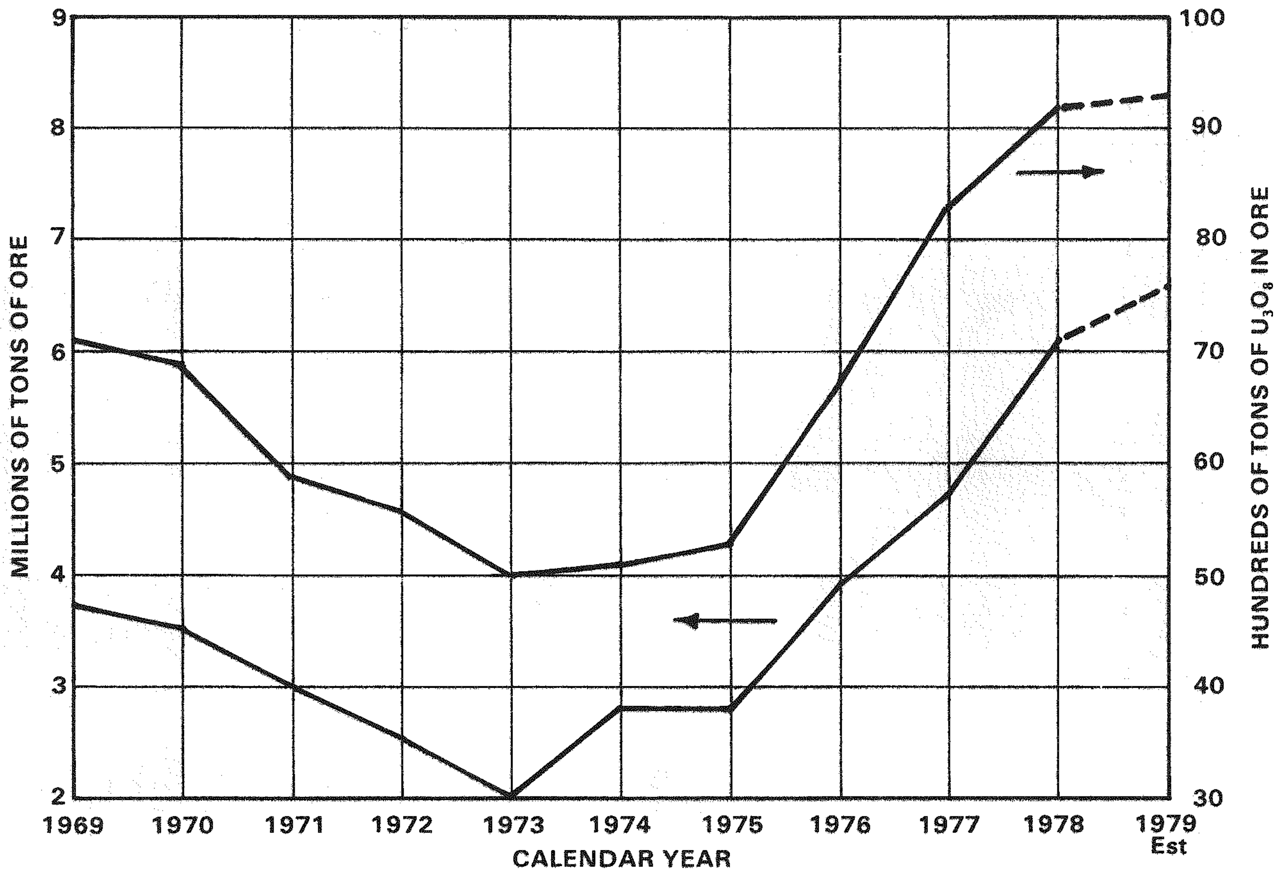

FIGURE 3. *Ore delivered from underground uranium mines*

Solution mining of uranium is continuing in Wyoming, Colorado, and Texas, with all of the larger operations in Texas. Most of the leaching is done with alkaline carbonate solutions containing an oxidant. Sulfuric acid was used for in situ leaching in the Shirley Basin, Wyoming, in the 1960s and is being tested at other locations.

Solution-mining depths now vary from 300 to 600 feet, and operations at greater depths are planned. It appears technically feasible to solution mine at depths of a few thousand feet, but the minimum economic size of orebody and minimum ore grade increase rapidly with depth. For independent operations (i.e. those not associated with ore-processing plants), the minimum economic size at depths less than 600 feet is about 500,000 pounds U_3O_8 in ore of 0.05 percent U_3O_8 content. Solution mining within a mile or two of a conventional uranium mill might be economically attractive with orebodies as small as 100,000 to 200,000 pounds U_3O_8 since recovery costs could be shared with those for recovering uranium from mined ore.

Two major items which contribute to solution-mining costs are monitoring during the leaching period and restoration of the leached-out zone after leaching is completed.

For environmental monitoring, wells are required, usually about 200 feet outside the perimeter of the area being leached and at 200-foot intervals. In addition to the monitor wells located in the formation being leached, monitor wells are required in the formations above and below the leaching zone. Water samples, collected from each monitor well at intervals of at least once per month, are analyzed to determine whether or not leach reagents have migrated from the solution-mining zone. If such an excursion occurs, leaching is discontinued until the problem is corrected. Excursions are few and generally should not represent any hazard to the public, because the chemicals used are not toxic, and low flow rates of ground waters allow adequate time to retrieve straying solutions.

Restoration of a leached-out zone is intended to displace leach chemicals and soluble uranium from that zone so that ground water will have essentially the same composition as it had before solution mining started. Depending upon the permeability of the aquifer, restoration may require from a few months to several years. Restoration is achieved by pumping ground water from the leached-out zone and may be accompanied by some treatment of this water to remove dissolved salts and recirculation of the treated water. Primary concern has been with ammonia. As one hydrologist pointed out, officials worry about 50 ppm of ammonia in ground water but permit 1,000 ppm of ammonia in bread.

Percolation leaching is closely related to in situ leaching. Early this year Durita Development Company completed successful percolation leaching of uranium mill tailings at Naturita, Colorado, to recover uranium and vanadium. This company had hoped to leach mill tailings from Durango, Colorado, but was unable to get necessary state permits. Union Carbide Corporation has continued heap leaching low-grade ore in Colorado and Wyoming, and Solution Engineering, Inc., has employed in situ leaching to recover uranium from mill tailings near Falls City, Texas.

URANIUM ORE PROCESSING

Conventional Mills

The 1979 uranium concentrate production is expected to contain 19,000 to 20,000 tons U_3O_8 (see figure 4). More than 90 percent of this or about 17,500 tons U_3O_8 will be recovered by processing some 16 million tons of ore in 21 conventional mills (see table 1 and figure 5). These mills have a capacity to produce nearly 20,000 tons U_3O_8 per year from ore of the grade now being mined. The balance of the U_3O_8 produced this year will be recovered as a byproduct or will come from solution mining, percolation leaching, or mine water. This year's production will be lower than we had expected at the beginning of the year because of long delays in licensing Cotter Corporation's 1,500 TPD (tons per day) acid leach mill at Canon City, Colorado, and an indefinite shutdown of United Nuclear Corporation's mill at Church Rock, New Mexico, after a break in the mill tailings dam in July.

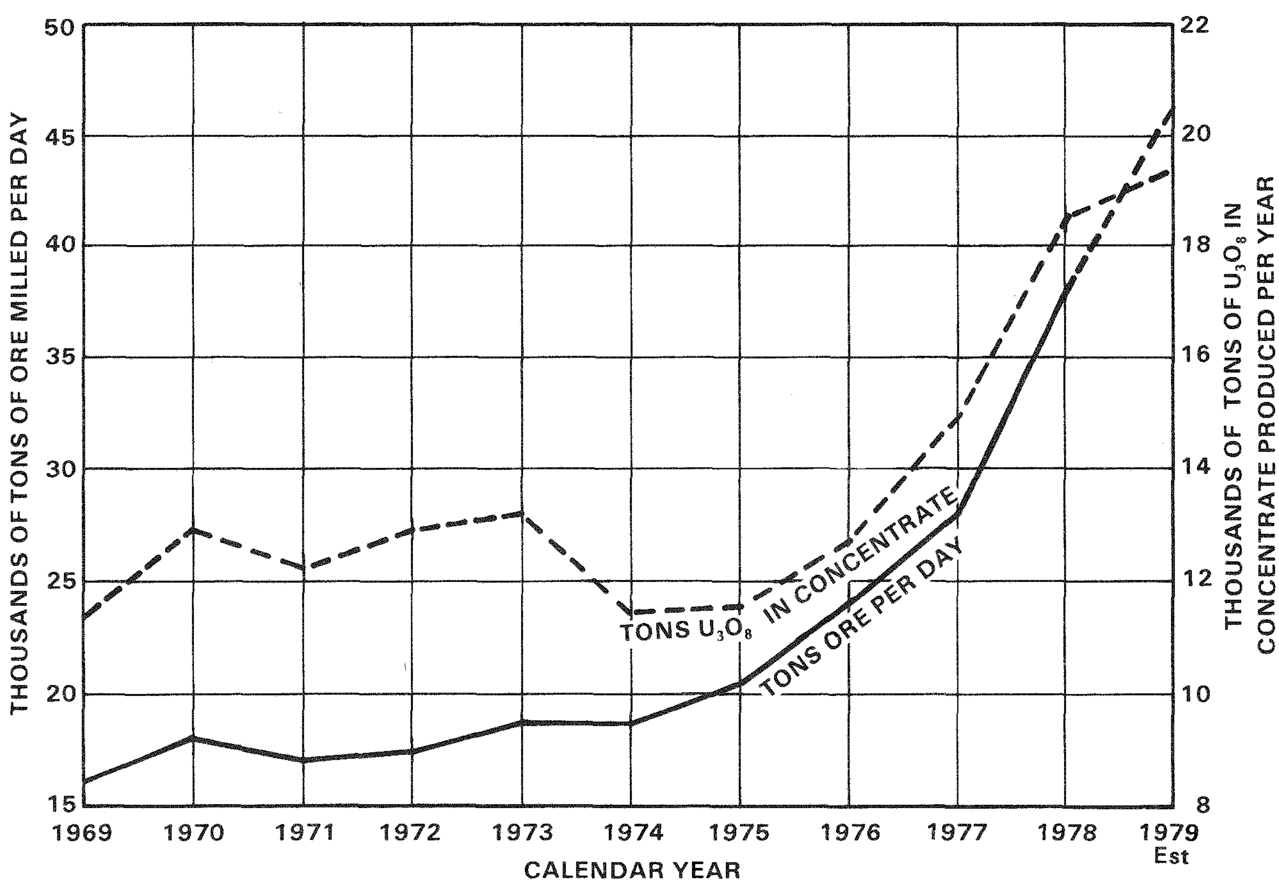

FIGURE 4. *Uranium ore processing rates and concentrate production*

TABLE 1. *Uranium ore processing mills*

COMPANY	LOCATION	CAPACITY (TONS ORE PER DAY)	PROCESS USED
Anaconda Copper Company	Grants, New Mexico	6,000	Acid leach, CCD, solvent extraction
Atlas Corporation	Moab, Utah	1,500	Carbonate leach, caustic precipitation & acid leach, solvent extraction
		2,000	Acid leach, CCD, solvent extraction
Bear Creek Uranium Company	Powder River Basin, Wyoming	2,500	Acid leach, CCD, solvent extraction
Chevron Resources Company	Panna Maria, Texas	3,200	Acid leach, CCD, solvent extraction
Conoco & Pioneer Nuclear, Inc.	Falls City, Texas	1,500	Acid leach, CCD, solvent extraction
Cotter Corporation	Canon City, Colorado	400	Acid leach, CCD, column ion exchange
Dawn Mining Company	Ford, Washington	3,000	Acid leach, CCD, solvent extraction
EXXON, U.S.A.	Powder River Basin, Wyoming	950	Acid leach, eluex
Federal-American Partners	Gas Hills, Wyoming		From wet-process phosphoric acid,
Freeport Uranium Recovery Corp.	Uncle Sam, Louisiana		solvent extraction
			From wet-process phosphoric acid,
Gardinier, Inc.	Tampa, Florida		solvent extraction
			In situ leaching, column ion
IEC Corporation	Three Rivers, Texas		exchange
		7,000	Acid leach, CCD, solvent extraction
Kerr-McGee Nuclear Corporation	Grants, New Mexico		In situ leaching, column ion exchange
Mobil Oil Corporation	Bruni, Texas	2,800	Acid leach, eluex
Pathfinder Mines Corporation	Gas Hills, Wyoming	1,800	Acid leach, CCD, column ion exchange
Pathfinder Mines Corporation	Shirley Basin, Wyoming	1,500	Acid leach, CCD, solvent extraction
Petrotomics Company	Shirley Basin, Wyoming	750	Carbonate leach, caustic
Rio Algom Corporation	La Sal, Utah		precipitation

TABLE 1. *Uranium ore processing mills (continued)*

COMPANY	LOCATION	CAPACITY (TONS ORE PER DAY)	PROCESS USED
Sohio Natural Resources Company	Seboyeta, New Mexico	1,660	Acid leach, CCD, solvent extraction
Solution Engineering, Inc.	Falls City, Texas		From uranium mill tailings, in situ leaching, column ion exchange
Union Carbide Corporation	Uravan, Colorado	1,300	Acid leach, CCD, column ion exchange
Union Carbide Corporation	Natrona County, Wyoming	1,200	Acid leach, eluex
United Nuclear Corporation	Church Rock, New Mexico	3,000	Acid leach, CCD, solvent extraction
UNC Recovery Corporation	Mulberry, Florida		From wet-process phosphoric acid, solvent extraction
United Nuclear Homestake Partners	Grants, New Mexico	3,000	Carbonate leach, caustic precipitation
U.S. Steel Corporation	George West, Texas		In situ leaching, column ion exchange
U.S. Steel-Niagara Mohawk	George West, Texas		In situ leaching, column ion exchange
Western Nuclear, Inc.	Wellpinit, Washington	2,000	Acid leach, CCD, solvent extraction
Western Nuclear, Inc.	Jeffrey City, Wyoming	1,700	Acid leach eluex
Wyoming Mineral Corporation	Bingham Canyon, Utah		From copper dump leach liquor, ion exchange
Wyoming Mineral Corporation	Bruni & Three Rivers, Texas		In situ leaching, ion exchange
Wyoming Mineral Corporation	Irigaray, Wyoming		In situ leaching, ion exchange
Wyoming Mineral Corporation	Pierce, Florida		From wet-process phosphoric acid, solvent exchange
	TOTAL	42,260	

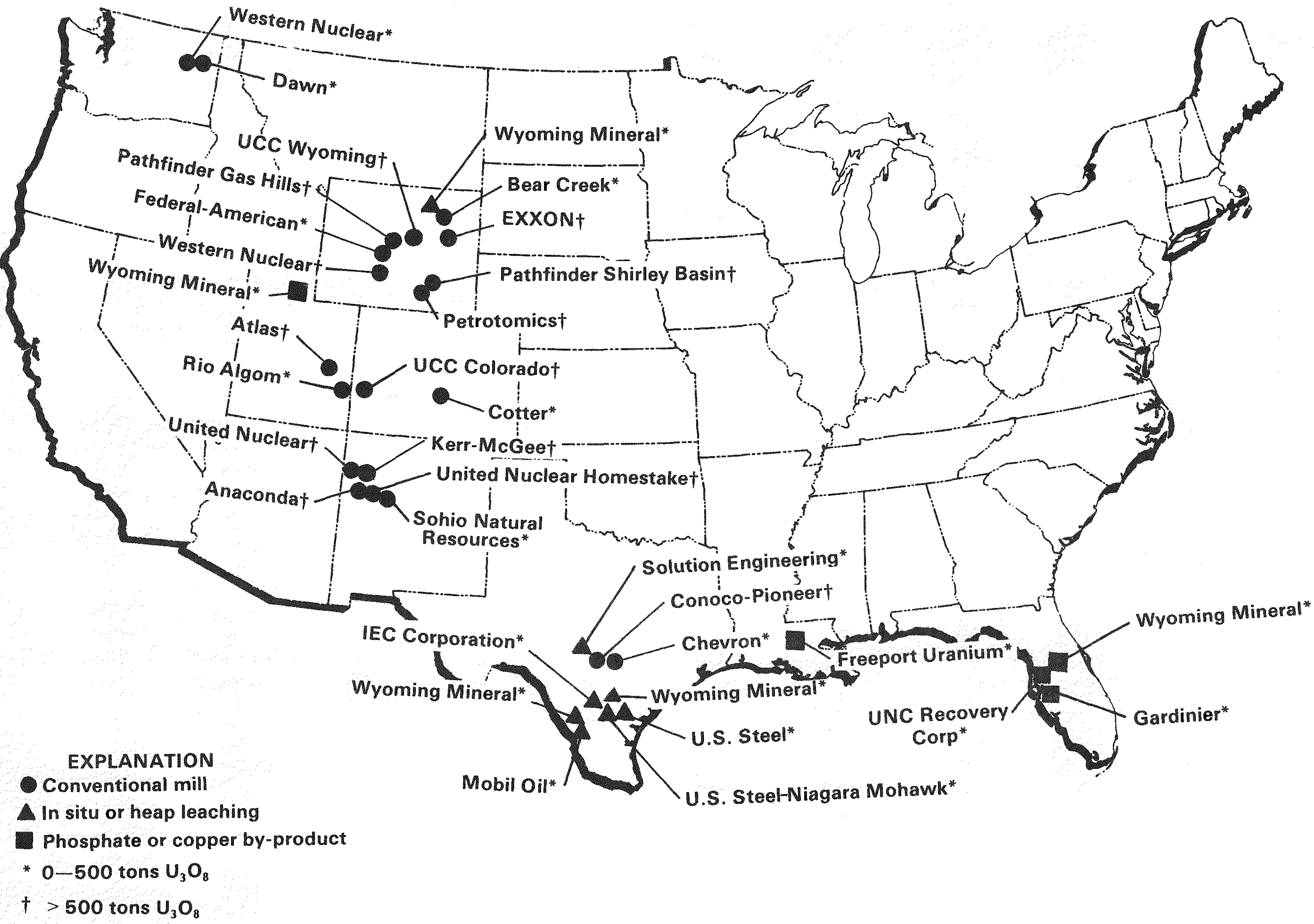

FIGURE 5. *Uranium mills in the United States*

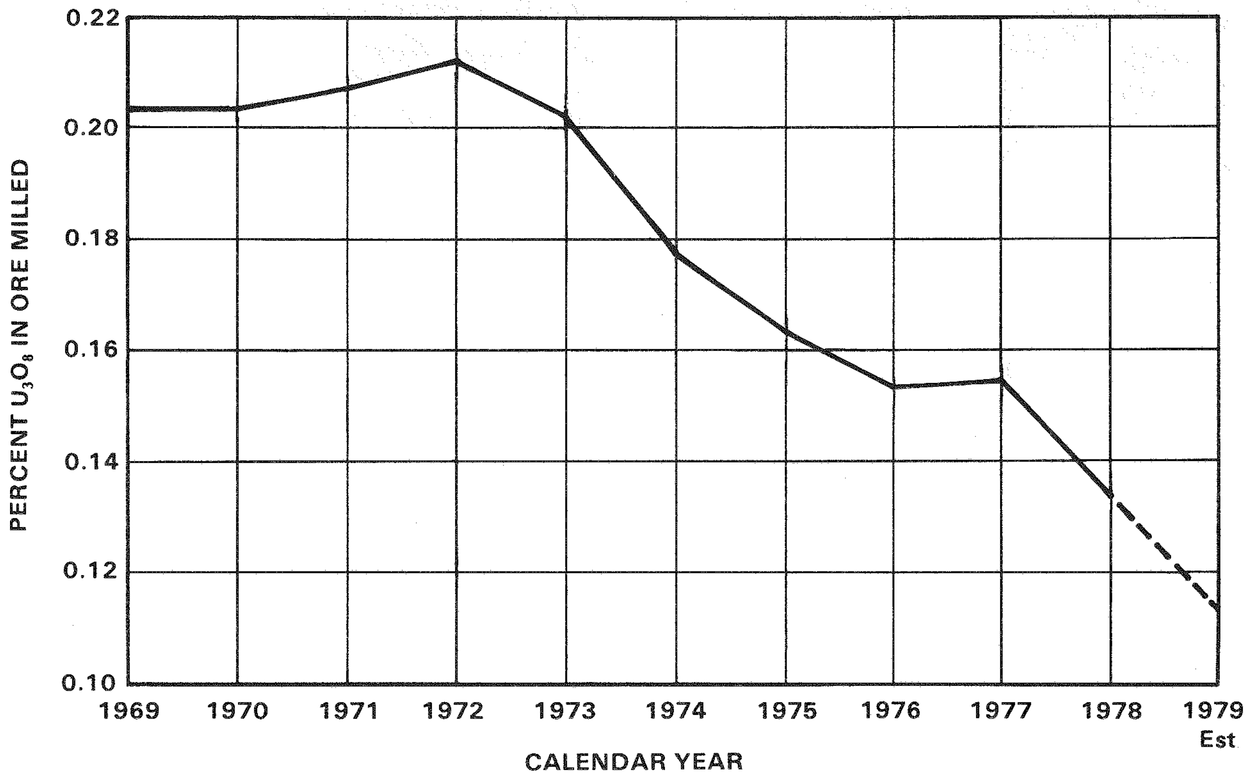

FIGURE 6. *Grade of uranium ore processed*

The average grade of ore processed apparently will drop from 0.133 percent U_3O_8 in 1978 to about 0.11 percent U_3O_8 in 1979 (see figure 6). Currently, monthly average feed grades for individual mills range from 0.03 to almost 0.30 percent U_3O_8. One third of the mills have average millfeed grades lower than the 0.10 percent U_3O_8 cut-off grade that was specified in the Atomic Energy Commission (AEC) ore purchase contracts of the 1950s and 1960s.

Mill recovery during each of the last 6 months was about 91 percent (see figure 7). This compares favorably with the 90.6-percent average from higher-grade ore in 1978. Most of the improved recovery in 1979 occurred at new mills as operators became more competent, and changes were made in equipment and/or operating conditions. Individual mill recoveries range from 75 to 99 percent. Eight of the mills recover less than 90 percent of the uranium in ore processed. Higher recoveries could be obtained, but the added costs of reagents, steam, and more equipment cannot always be justified at the contract prices that many companies are receiving for uranium concentrate. A few companies are making changes in their mills to increase uranium recoveries.

Chevron Resources Company began processing ore at its 2,500 TPD mill at Panna Maria, Texas, in February, and Cotter started up its new 1,500 TPD mill at Canon City, Colorado, in September. Construction continues at the 2,000 TPD mill of Bokum Resources Corporation near Marquez, New Mexico. In Wyoming, Pathfinder Mines Corporation is expanding its Lucky Mc mill, and Bear Creek Uranium Company expanded its mill to 2,000 TPD.

Considerable progress was made during the last 12 months toward obtaining licenses for construction of new uranium mills. Final environmental statements were issued for the following new projects:

Energy Fuels Nuclear, Inc. White Mesa Uranium Project San Juan County, Utah	2,000 TPD
EXXON Minerals Company, U.S.A. Highland Uranium Solution Mining Project Converse County, Wyoming	375 Tons U_3O_8/Yr
Homestake Mining Company Pitch Project Saguache County, Colorado	600 TPD

Minerals Exploration Company
Sweetwater Uranium Project
Sweetwater County, Wyoming — 3,000 TPD

Plateau Resources, Ltd.
Shootering Canyon Uranium Project
Garfield County, Utah — 750 TPD

Tennessee Valley Authority
Morton Ranch Uranium Mill
Converse County, Wyoming — 2,000 TPD

Other mills which have been announced include:

Phillips Petroleum Co.
Nose Rock, New Mexico — 2,500 TPD

Pioneer-Uravan, Inc.
Slick Rock, Colorado — 1,000 TPD

BYPRODUCT URANIUM

Wet-Process Phosphoric Acid

A million pounds U_3O_8 were recovered from wet-process phosphoric acid in the 1950s and early 1960s. Production was discontinued at that time because the AEC did not renew contracts to purchase uranium concentrate produced from phosphates. More recently, Oak Ridge National Laboratory and others developed new processes or improved the processes used previously. There was a small uranium production from phosphoric acid in 1976, 1977, and 1978. By the end of 1978, three companies were producing uranium from phosphoric acid, and there will be five companies producing by the end of this year. These companies are listed in table 2.

The Gardinier recovery began late this spring, and IMC is close to, if not in, the start-up phase of uranium recovery. In addition to the companies listed, IMC is building primary uranium recovery units at C. F. Industries, Inc., phosphoric acid plants at Bartow and Plant City, Florida, for start up by late 1980, and Earth Sciences, Inc., is starting up a uranium recovery plant at the Calgary, Alberta, plant of Western Cooperative Fertilizers, Ltd., which processes phosphate rock from the western United States.

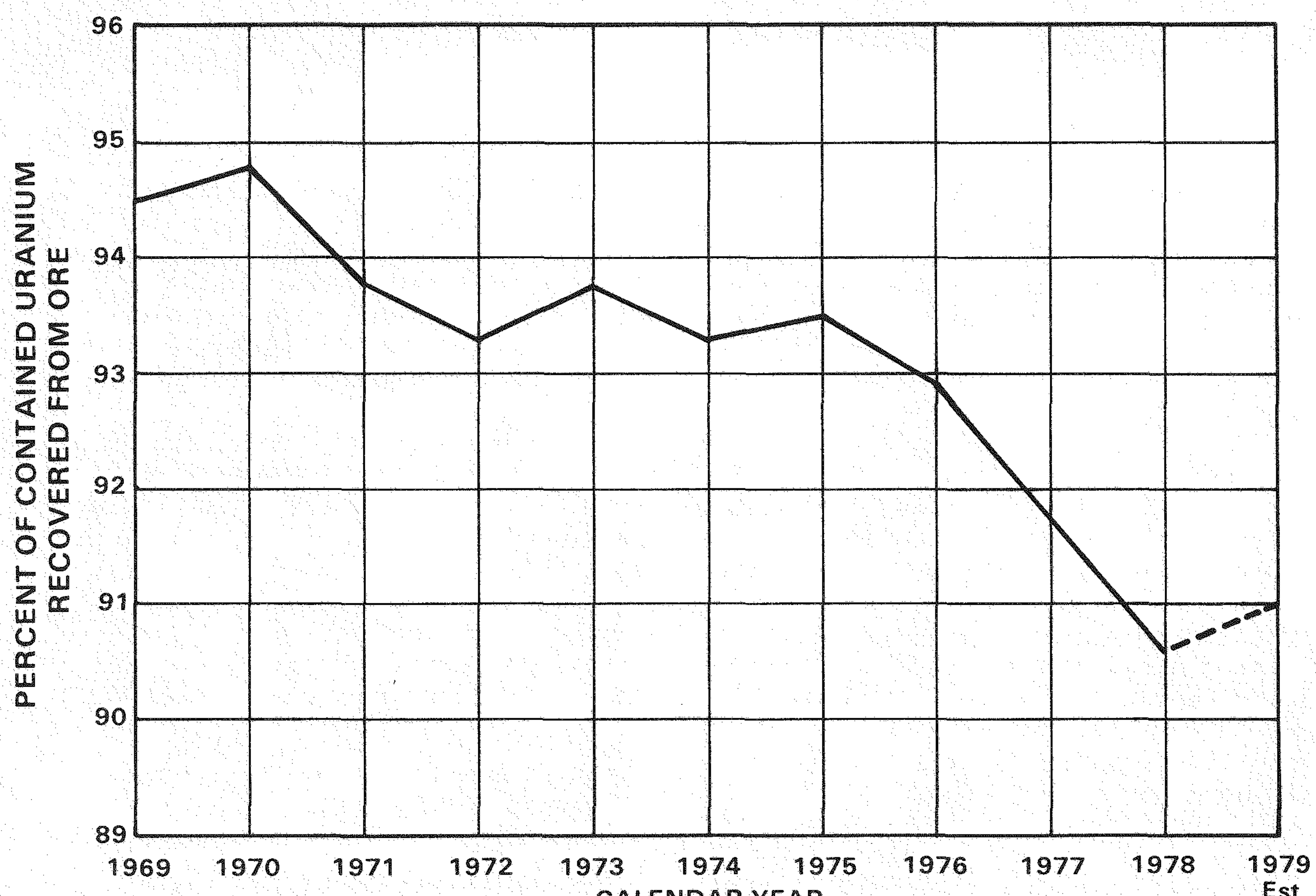

FIGURE 7. *Recovery of uranium from ore processed*

TABLE 2. *Companies producing uranium from phosphoric acid by end of 1978*

Company	Location	Capacity Tons U_3O_8/Yr
Freeport Uranium Recovery Co.	Uncle Sam, LA	345
Gardinier, Inc.	Tampa, FL	220
IMC Chemicals Corp.	Mulberry, FL	375
Wyoming Mineral Corp. (at Farmland Industries)	Pierce, FL	200
UNC Recovery Corp. (at W. R. Grace & Co.)	Mulberry, FL	140

Beker Industries Corp. and Mono Power Company, a subsidiary of Southern California Edison, have announced plans to build a uranium recovery pilot plant at Beker's Conda, Idaho, phosphoric acid plant, and if the pilot tests are successful, a commerical unit will be built.

Freeport Uranium Recovery Co. and Agrico Chem-Williams Co. are negotiating a contract for Freeport to install a primary uranium recovery circuit at Agrico's wet-process phosphoric acid plant at Donaldsonville, Louisiana. If the circuit is built, the uranium will be sent to Freeport's Uncle Sam, Louisiana, plant for purification and recovery.

All of the plants recovering uranium from wet-process phosphoric acid use solvent extraction processes in which an extractant dissolved in a kerosene-type diluent is contacted with uranium-bearing phosphoric acid to extract the uranium. As extractants, Gardinier, Inc., uses octyl pyrophosphoric acid (OPPA); Earth Sciences, Inc., and UNC Recovery Corporation use octylphenyl acid phosphate (OPAP); and the other companies use di (2-ethylhexyl) phosphoric acid (DEPA) with a synergistic additive, trioctylphosphine oxide (TOPO).

Wet-process phosphoric acid made from central Florida phosphate rock contains about 1 pound U_3O_8 per ton P_2O_5, and about 90 percent of this can be recovered with present technology. Phosphoric acid made from phosphate rock from other areas of the United States contains lower uranium concentrations, and percent uranium recovery will be lower.

Uranium production from phosphoric acid will be about 1 million pounds U_3O_8 in 1979 and 2 million pounds in 1980. Frank E. McGinley discussed the uranium capacity of domestic phosphoric acid plants in the paper which preceded this one.

Copper Leaching

A few years ago the Salt Lake City Metallurgy Research Center of the U.S. Bureau of Mines anallyzed liquor samples from a number of copper dump-leaching operations in the western United States. These samples contained 1 to 10 ppm of uranium. On the basis of the information obtained, the Bureau estimated that as much as 1,000 tons U_3O_8 per year might be recovered from copper-leach liquors. The Bureau studied methods of recovering this uranium by ion exchange and worked with Kennecott Copper Corporation at Bingham Canyon, Utah, on a pilot plant study of uranium recovery. Afterward, Kennecott made some larger scale tests. Based on these and other tests, Wyoming Mineral Corporation built a prototype recovery unit at Kennecott's Bingham Canyon operation in 1978, and following some equipment modifications, the unit is operating at near the design capacity of 143,000 pounds U_3O_8 per year.

In Arizona, Anamax Mining Co. near Tucson is completing a plant to recover about 400 pounds U_3O_8 per day from copper oxide-leach liquor, and Phelps-Dodge Corp. at Bisbee is studying the feasibility of uranium recovery from dump-leach liquor.

We do not anticipate a large production of uranium as a byproduct from copper recovery during the next 3 years but expect that more companies will consider uranium recovery as the technology is further developed.

Beryllium Byproduct

Brush-Wellman, Inc., is building a recovery circuit in its beryllium mill at Lynndyl, Utah, to recover 20,000 to 40,000 pounds U_3O_8 per year as a byproduct. This circuit is scheduled to start up toward the end of 1979.

The beryllium ore contains 0.002 to 0.015 percent U_3O_8. As the ore is processed, the uranium is concentrated and eliminated from the process stream in the barren mill filtrate waste stream. This liquor will be concentrated by solar evaporation, and the uranium will be recovered by solvent extraction during a three-month campaign once a year.

CONCLUSIONS

Although 1979 will be a record year for domestic uranium mining and milling, the slight increase over 1978 in uranium concentrate production is being obtained at the expense of mining and milling 15 percent more ore to compensate for lower ore grades. We anticipate that in 1980 the ore grade will remain at about 0.11 percent U_3O_8 and that mine-mill production will increase by less than 10 percent. Although mills for Energy Fuels Nuclear, Inc., and Plateau Resources, Ltd., should be completed by late 1980, the only significant new conventional production next year is expected to come from the Bokum Resources Corporation mill. There should be significant increases in uranium recovery by solution mining and from phosphoric acid.

URANIUM PRODUCTION CAPABILITY IN THE UNITED STATES

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October 1979

INTRODUCTION

The uranium production capability discussed in this paper extends from 1979 through 2008. It follows the "could" production capability format, the definition of which provides for an unconstrained market for product and a willingness by the industry to make timely decisions to explore for uranium, develop ore deposits, construct mining and milling facilities, and produce uranium concentrate. The estimate assumes that financing, manpower, materials, and other supporting elements would be available as needed and that environmental and regulatory permitting and licensing constraints would remain at the level which existed at the time of the study. This is, of course, not an estimate of future production; it is, rather, a projection of the upper limit to produce from currently available resources under the given assumptions.

The principal reason for selecting the $50 per pound resource base for the 1979 study was to provide government planners and officials with needed information on the amount of domestic uranium that could be available to the nation from resources having costs higher than $30 per pound. This information is used in planning strategies relating to alternate fuel technology, recycling of uranium, enrichment considerations, nonproliferation aspects of recycling plutonium and timing of breeder reactors, and international matters.

This "could" capability estimate is similar in type to those presented in past Uranium Industry Seminars held in Grand Junction. In recent years, the main differences between papers from year-to-year have been the quantities and cost levels of resources on which the production capabilities were based. Changes in the resource base have been due to changes in the forward cost category ($10, $15, $30, or less, per pound U_3O_8) selected and changes in resource estimates resulting from industry exploration and data available from the National Uranium Resource Evaluation (NURE) program. In 1976, a maximum cost of $15 per pound U_3O_8, or less, resources was used primarily because the grade of the $15 resources was about the same average grade (about 0.15 percent U_3O_8) as the industry was *then* mining. In 1977, the production capability of the industry was estimated from the $30 per pound resource base because it appeared that *future* prices could support production from that resource base, which in 1977 represented an average grade of about 0.09 percent U_3O_8. Many of the contracts being negotiated in 1977 for delivery in the early 1980s were calling for prices greater than $40 per pound.

URANIUM RESOURCES AVAILABLE AT $50 PER POUND U_3O_8

Assessment of the production capability of the uranium exploration, mining, and milling industry is based primarily on the uranium reserves and probable potential uranium resources as estimated by the Grand Junction Office. Also included in the resource base is the uranium expected to be obtained as a byproduct of wet-process phosphoric acid produced from phosphate rock, as a byproduct of certain copper mining operations where uranium is obtained from the acid leaching of uranium-bearing oxidized copper ores and waste dumps, and as a byproduct of beryllium operations.

A summary of the total domestic resources estimated as of January 1, 1979, is shown in table 1. Only that quantity of the byproduct uranium that could be produced within the next 30 years is shown.

RESOURCE UTILIZATION ASSUMPTIONS

Table 2 summarizes the resources which were utilized during the 30-year study period, 1979–

TABLE 1. *Uranium resources as of January 1, 1979, at $50 per pound U_3O_8*

	Tons Ore (x 10^6)	Grade % U_3O_8	Tons U_3O_8 (x 10^3)	% of Total Resources
Reserves	1,300	0.071	920	22
Potential:				
Probable			1,505	35
Possible			1,170	27
Speculative			550	13
Byproduct			137*	3

*Estimated "could" production capability from phosphate and copper during 1979–2008.

2008. Possible and speculative resources are not included in this production capability estimate. Of the uranium resources included in the study (approximately 2.6 million tons U_3O_8) about 36 percent are reserves, about 59 percent probable potential resources, and about 5 percent byproduct uranium.

A large portion of the uranium that could be produced over the next 30 years, particularly during the latter portion of the period, would depend upon the industry's success in converting potential resources to reserves. The estimated cumulative lead times to convert probable potential resources to reserves and to uranium concentrate are shown on figure 1. The figure shows that the first 200,000 tons of $50 probable potential resources could be converted to reserves by the end of 1980 and that an additional 13 years would be required to convert the "ore" to concentrate (Case A). The figure also shows that the next 400,000 tons of potential resources could be converted to reserves by the end of 1985 and to uranium concentrate by the end of 2002, a period of 17 years between conversion of probable potential to reserves and production of U_3O_8 in concentrate (Case B). Table 3 shows ranges of lead times for the various activities leading to production of U_3O_8 in concentrate for the indicated mine development methods.

TABLE 2. *Uranium resource utilized from 1979 through 2008—$50/lb "could" capability*

	Tons Ore (x 10^6)	Grade % U_3O_8	Tons U_3O_8 (x 10^3)	% of Resource	U_3O_8 in Concentrate: Tons (x 10^3)	U_3O_8 in Concentrate: % of Total
Ore Reserves:						
Conventional	988	0.080	795			
Nonconventional*			71			
Total			866	94	786	43
Probable Potential Resources:						
Conventional	918	0.090	824			
Nonconventional*			189			
Total			1,013	67	913	50
Byproduct					137	7
Total					1,836	100

*Includes heap leaching and solution mining.

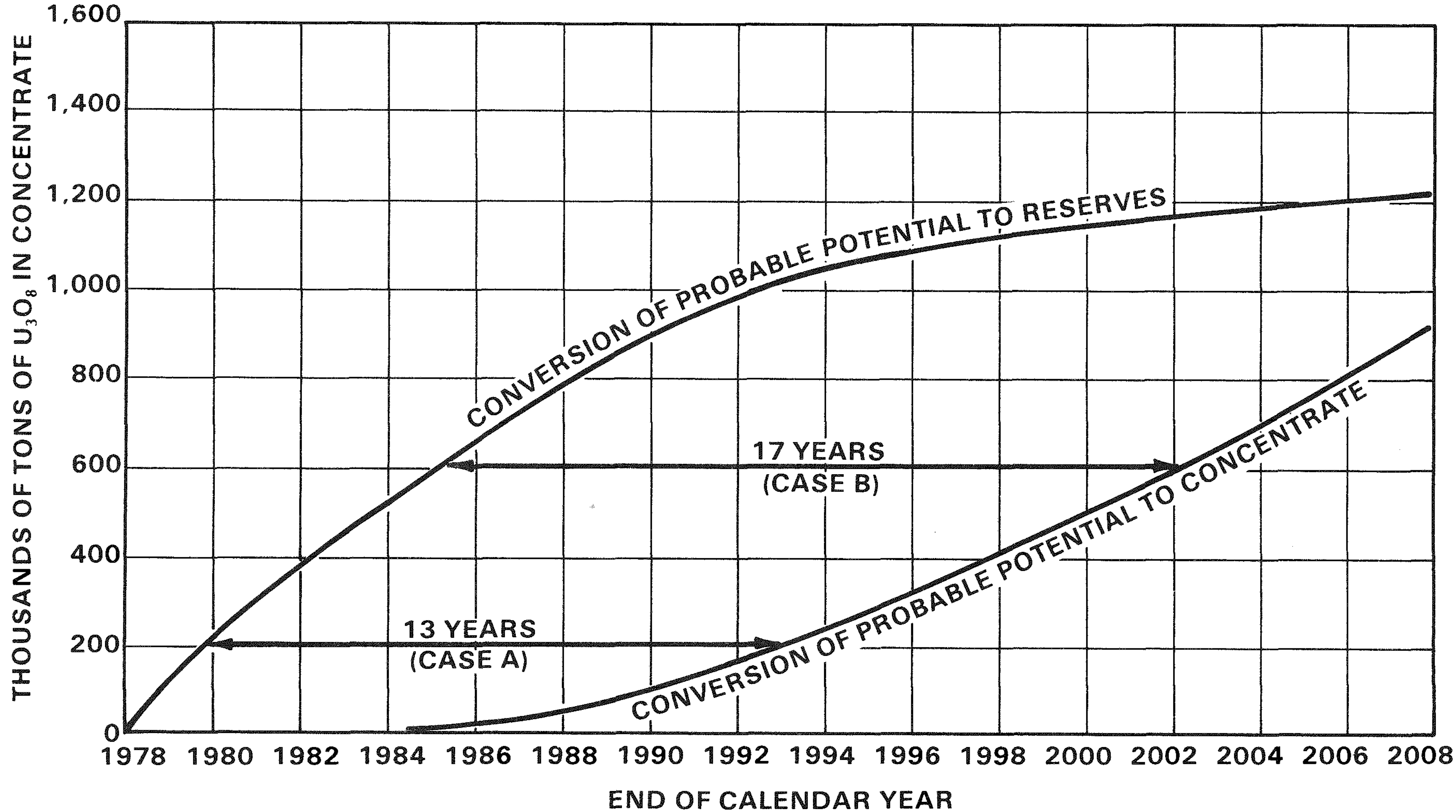

FIGURE 1. *Estimated time to convert 1/1/79 $50/lb probable potential resources to reserve and to concentrate*

TABLE 3. *Time required for activities[1] leading to production of U_3O_8 in concentrate*

Activities	Range of Time to Perform, Years[2]
1. Feasibility analysis	1-2
Environmental studies	1-2
Property consolidations	0-3
2. Overall project review	0-1
Financing	1-2
3. Property & mine development	
a. Solution mining	3-5
b. Open pit	1-3
c. Underground	
1. <1,000-ft depth	3-5
2. 2,000-3,000-ft depth	4-7
4. Mill construction	1-2

[1]Activities occurring after conversion of resources to reserves.
[2]Some of these activities may take place concurrently.

Not all of the reserves and probable potential resources shown on table 1 are assumed to be utilized within the 30-year time constraint of this estimated period. A large portion of the probable resources could be converted to reserves within the next 30 years; however, only a portion of the new "reserves" could be available for production. Also, a small portion of today's underground reserve could still be in the ground at the end of the period. The lives of many of the production centers could extend beyond the 30-year period, and economics might dictate that newly found reserves would be scheduled for production before the "old" reserves that are known today are mined.

THE 1979 $50 PER POUND "COULD" PRODUCTION CAPABILITY ESTIMATE

As in prior production capability estimates, the basic building blocks are production centers. A production center is an economic unit which consist of mining facilities, an ore processing mill, and reserves and/or probable potential resources. The geographical locations of the 83 production centers included in the 1979 $50 per pound production capability estimate are shown on figure 2.

Production centers are categorized into four classes, depending upon the relative certainty of future production. Class 1 centers include the existing mills, with supporting mines and other facilities, at which concentrate is being produced at the time the capability estimate is made. Ownership of the facilities and tributary sources can readily be identified. Production costs can reasonably be defined, and future production is well assured. Class 2 centers include those uranium mills and supporting resources for which construction commitments are evident and mine development is underway or has been announced. Although the ownership is established, production costs and even the quantities to be produced are less certain than for Class 1 centers. Class 2 centers generally are converted to Class 1 centers within 3 years. This year's estimate recognized 34 Class 1 production centers and 17 Class 2 production centers. Tables 4a and 4b list the names of the companies associated with these production centers and the locations of the mills.

Class 3 and 4 production centers apply to mills which may be constructed at a future date. Class 3 centers are postulated uranium mills in regions where the amount and grade of reserves justify production but where commitments for mill construction are not yet evident. Environmental studies and reports and mine and mill installations are estimated to require 3 to 10 years. Class 4 centers are possible centers postulated for areas in which reserves presently are insufficient to support production facilities, but where exploration and/or geologic evidence has indicated sufficient "probable" potential resources to warrant the assumption of eventual production. The assumed cumulative lead times required to develop reserves and construct mining and milling facilities for $50 per pound Class 4 centers generally range from 8 to 14 years. The major activities which contribute to the lead times for production from new centers are summarized in table 3. Class 3 and Class 4 production centers are postulated without strict regard to current land ownership. In some instances, it appears that land holdings would have to be consolidated, either through buyout or joint-venture, before construction of a production center would actually begin. It is recognized that time consuming negotiations may be necessary to effect these consolidations. This year's production capability estimate postulates 16 Class 3 production centers and 16 Class 4 production centers. Tables 4c and 4d list the companies, areas, or resources associated with these production centers and their locations.

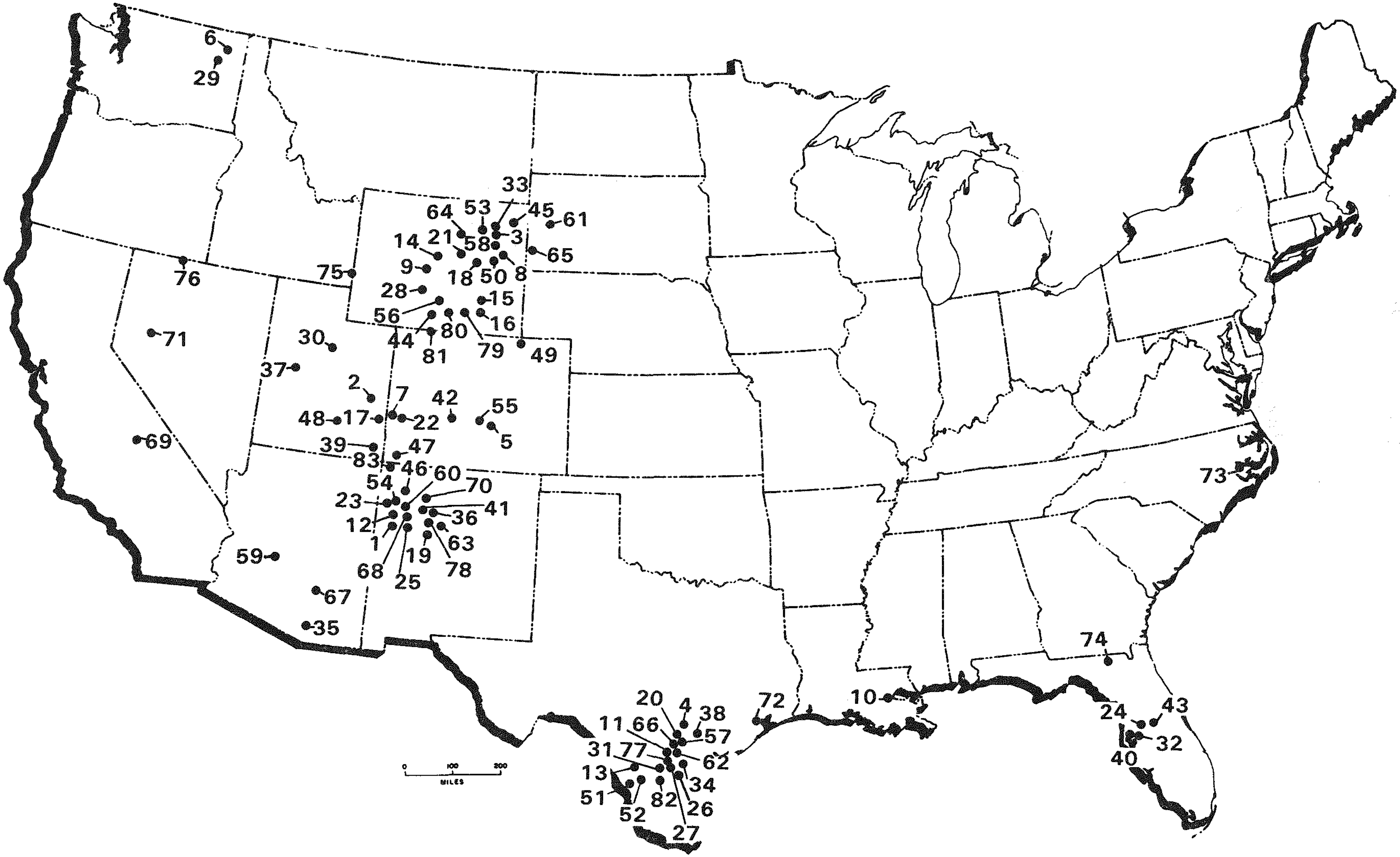

FIGURE 2. *Production centers in the United States—U_3O_8 in concentrate at $50/lb*

TABLE 4a. *Class 1 production centers*

Associated Company	Location
1. Anaconda Copper Company	Grants, New Mexico
2. Atlas Corporation	Moab, Utah
3. Bear Creek Uranium Company	Powder River Basin, Wyoming
4. Conoco and Pioneer Nuclear, Inc.	Falls City, Texas
5. Cotter Corporation	Canon City, Colorado
6. Dawn Mining Company	Ford, Washington
7. Durita Development Company	Naturita-Durango, Colorado
8. EXXON Company, U.S.A.	Powder River Basin, Wyoming
9. Federal-American Partners	Gas Hills, Wyoming
10. Freeport Uranium Recovery Company	Uncle Sam, Louisiana
11. IEC Corporation	Three Rivers, Texas
12. Kerr-McGee Nuclear Corporation	Grants, New Mexico
13. Mobil Oil Corporation	Bruni, Texas
14. Pathfinder Mines Corporation	Gas Hills, Wyoming
15. Pathfinder Mines Corporation	Shirley Basin, Wyoming
16. Petrotomics Company	Shirley Basin, Wyoming
17. Rio Algom Corporation	La Sal, Utah
18. Rocky Mountain Energy Company	Nine Mile-Reno, Wyoming
19. Sohio Natural Resources-Reserve Oil and Minerals	Laguna, New Mexico
20. Solution Engineering, Inc.	Falls City, Texas
21. Union Carbide Corporation	Gas Hills, Wyoming
22. Union Carbide Corporation	Uravan, Colorado
23. United Nuclear Corporation	Church Rock, New Mexico
24. UNC Recovery Corporation	Mulberry, Florida
25. United Nuclear-Homestake Partners	Grants, New Mexico
26. United States Steel Corporation	George West, Texas
27. U.S. Steel-Niagara Mohawk	George West, Texas
28. Western Nuclear, Inc.	Jeffrey City, Wyoming
29. Western Nuclear, Inc.	Wellpinit, Washington
30. Wyoming Mineral Corporation	Bingham, Utah
31. Wyoming Mineral Corporation	Bruni, Texas
32. Wyoming Mineral Corporation	Pierce, Florida
33. Wyoming Mineral Corporation	Irigaray, Wyoming
34. Wyoming Mineral Corporation	Three Rivers, Texas

Numbers shown on left side of the table are keyed to production center locations on figure 2.

Table 5 shows the estimates of future uranium concentrate production for each year from each class of production center. Table 6 summarizes the reserves and potential resources that could be mined and milled by each class of production center. Uranium concentrate that could be produced as byproduct from phosphate and copper operations is also shown.

Figure 3 summarizes the annual production capability associated with each class of production center. Expansions and renovations of existing production centers could result in attaining a production rate of 32,000 tons U_3O_8 in concentrate per year in 1990 and sustain that level of production throughout the period of the estimate. Figure 4 summarizes the annual production capability by type of resource. Note that the present reserves could support a production rate of 35,000 tons or more of U_3O_8 in concentrate per year from about 1983 through the early 1990s.

The data presented in figures 3 and 4 have been rearranged in figures 5 and 6 to show cumulative production capability. Figure 5 contrasts the production capability from the various classes of production centers, and figure 6 illustrates the

TABLE 4b. *Class 2 production centers*

Associated Company	Location
35. Anamax Mining Company	Tucson, Arizona
36. Bokum Resources Corporation	Marquez, New Mexico
37. Brush-Wellman, Inc.	Lynndyl, Utah
38. Chevron Resources Company	Panna Maria, Texas
39. Energy Fuels Nuclear, Inc.	Blanding, Utah
40. Gardinier, Inc.	Tampa, Florida
41. Gulf Mineral Resources Company	San Mateo, New Mexico
42. Homestake Mining Company	Marshall Pass, Colorado
43. IMC Chemicals	Mulberry, Florida
44. Minerals Exploration Company	Red Desert, Wyoming
45. Nuclear Dynamics, Inc.	Sundance, Wyoming
46. Phillips Uranium Corporation	Nose Rock, New Mexico
47. Pioneer-Uravan, Inc.	Slick Rock, Colorado
48. Plateau Resources, Ltd.	Hanksville, Utah
49. Power Resources Corporation	Grover, Colorado
50. Tennessee Valley Authority	Morton Ranch, Wyoming
51. Uranium Resources, Inc.	Bruni, Texas

Numbers shown on left side of the table are keyed to production center locations on figure 2.

production capability from uranium reserves versus production capability from potential resources.

The production capability is shown by mining method in figure 7. The net contribution of open-pit mining to the total uranium concentrate production could increase by only a relatively small amount during the period. However, due to a continuing reduction in the grade of surface-mined ore, open-pit mining could increase nearly 300 percent in terms of tons of ore mined. The majority of the increase in uranium concentrate production would come from new underground mines and nonconventional sources.

TABLE 4c. *Class 3 production centers*

Associated Company/Area	Located
52. Anaconda Copper Company	Rhode Ranch, Texas
53. Cleveland-Cliffs Iron Company	Pumpkin Buttes, Wyoming
54. Conoco, Inc.	Crownpoint, New Mexico
55. Cyprus Mines–Westinghouse	Tallahassee Creek, Colorado
56. East Crooks Gap	Wyoming
57. Everest Exploration	Hobson, Texas
58. Kerr-McGee Nuclear Corporation	Powder River Basin, Wyoming
59. Minerals Exploration Corporation	Wickenburg, Arizona
60. Mobil Oil Corporation	Crownpoint, New Mexico
61. North Black Hills	South Dakota
62. Nuclear Development Company	Star City, Texas
63. Rio Puerco	New Mexico
64. Rocky Mountain Energy Company	Copper Mountain, Wyoming
65. South Black Hills	South Dakota
66. Sunoco Energy Development Co.	Hobson, Texas
67. Wyoming Mineral Corporation	Miami, Arizona

Numbers shown on left side of the table are keyed to production center locations on figure 2.

TABLE 4d. *Class 4 production centers*

Source/Area	Location
68. Ambrosia Lake	New Mexico
69. Coso	California
70. East Chaco Canyon	New Mexico
71. Fernley	Nevada
72. Phosphate	Gulf Coast (Tex, La., Miss.)
73. Phosphate	North Carolina
74. Phosphate	Northern Florida
75. Phosphate	Western U.S. (Idaho,Wyo.)
76. McDermitt	Nevada
77. McMullen	Texas
78. Mt. Taylor	New Mexico
79. N.E. Great Divide Basin	Wyoming
80. N.W. Great Divide Basin	Wyoming
81. Sand Wash Basin	Wyoming-Colorado
82. San Diego	Texas
83. Shiprock	New Mexico

Numbers shown on left side of the table are keyed to production centers locations on figure 2.

The contribution from nonconventional sources could grow rapidly and might exceed 20 percent of the total production capability during the early 1980s. The sources of nonconventionally recoverable uranium are further analyzed in figure 8. Solution-mining production capability could grow to 10,000 tons U_3O_8 per year by 1989. Although the solution mining industry is now in the commercial stage, the growth of this industry will be uncertain until a sufficient base of commercial experience is acquired. Recovery of uranium from wet-process phosphoric acid could develop to 4,000 tons U_3O_8 per year in the next 15 years and to 5,000 tons U_3O_8 in 20 years. Estimates of the amount of uranium that could be derived from phosphate operations are uncertain because the amount of phosphate processed is dependent on the fertilizer market. The recovery of uranium by heap leaching and as byproducts of copper and beryllium operations could contribute about 1,000 tons of U_3O_8 per year by 1986, but are not expected to be more than 1,000 tons per year throughout the remainder of the period of the estimate.

The average grade of the ores that would be mined and processed in a conventional manner is depicted in figure 9. A drop in average grade in the 1979–86 period is projected as expiring low-price contracts allow established producers to lower cut-off grades and as new low-grade operations are put into production. As indicated by the figure, if conditions warrant and if the industry elects to produce from the $50 per pound resource base, the average grade of such ores could be expected to decline until it levels off at about 0.08 percent U_3O_8 with the average grade from underground mining dropping to about 0.10 percent and from open-pit mining to about 0.06 percent.

Because of the low grade of the ore that represents the $50 per pound resources, the quantity of ore that would need to be mined and milled to produce the U_3O_8 in concentrate shown in the "could" production capability estimate is nearly 6 times higher by the mid 1900s than the quantity that is presently being mined and milled. Figure 10 shows this growth and compares it with actual ore mined and fed to process from 1970 through 1978. The percentage change in the tons of ore that would need to be mined and milled over the previous year is illustrated by figure 11. This figure shows about a 36-percent increase in tons of ore mined and milled in 1978 as compared to 1977. The rate changes rapidly downward with some interim upward deviations during the periods 1979–83 and 1986–89. The first upward deviation would be due to Class 2 and Class 3 production centers starting production and the second because of Class 4 centers starting production.

BLENDING OF PRESENT OPERATIONS TO "COULD" CAPABILITY

Each year, the U.S. Department of Energy's (DOE) Grand Junction Office requests that uranium producers attending industry conferences

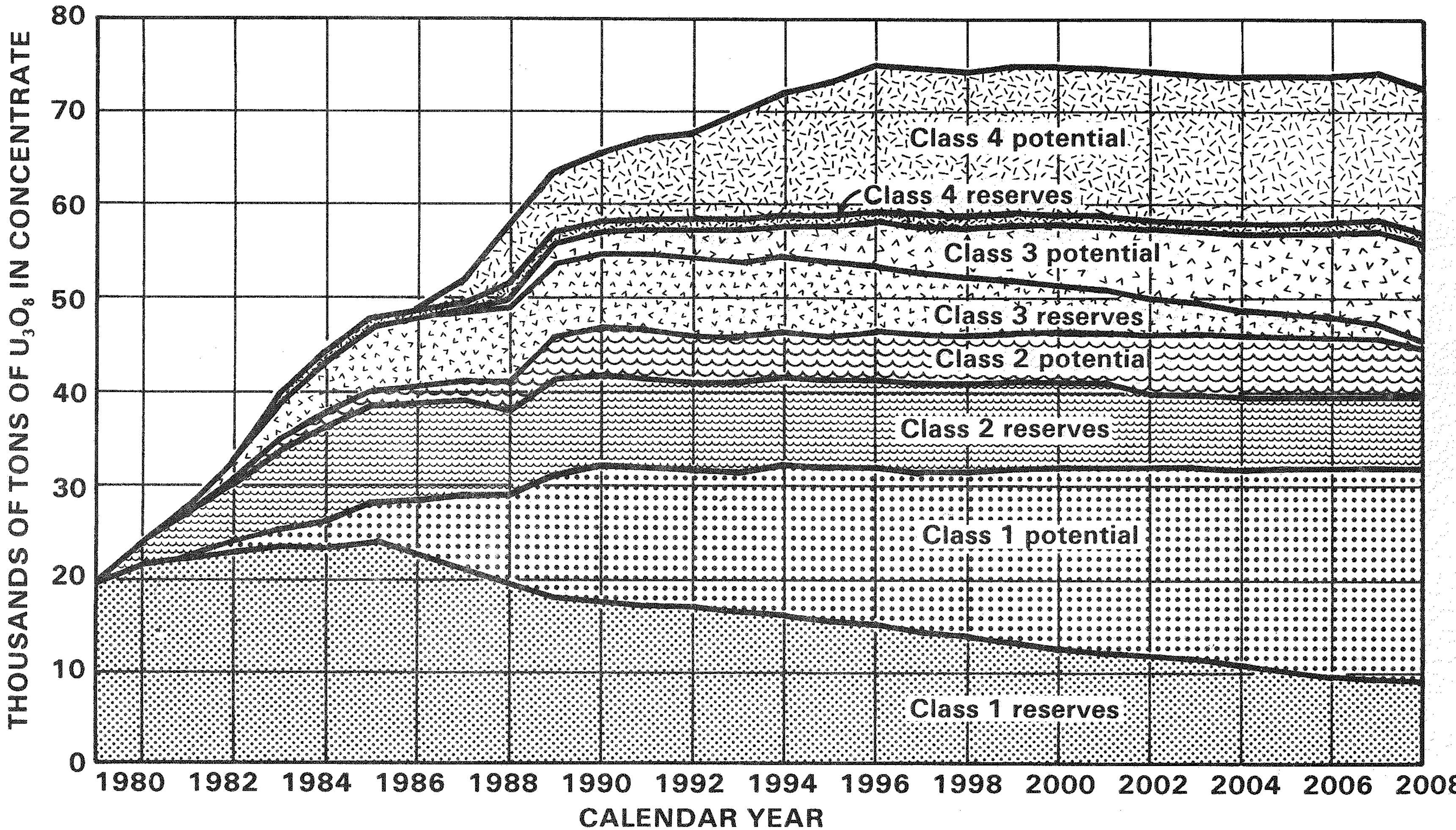

FIGURE 3 . *Estimated $50/lb "could" production capability—annual by production center class*

TABLE 5. *Estimated "could" production capability as of 1/1/79—U_3O_8 in concentrate at a cost of $50/lb—by production center class*

Year	Production, Tons U_3O_8 in Concentrate, (x 10^3) Class 1	Class 2	Class 3	Class 4	Total
1979	19	1	0	0	20
1980	22	2	0	0	24
1981	22	4	0	0	26
1982	24	6	2	0	32
1983	25	10	4	0	39
1984	26	12	6	1	45
1985	28	12	7	1	48
1986	28	12	7	1	48
1987	29	12	7	3	51
1988	29	12	9	8	58
1989	31	15	10	8	64
1990	31	15	10	9	65
1991	31	15	11	10	67
1992	32	15	11	10	68
1993	31	15	12	12	70
1994	32	14	12	14	72
1995	32	14	12	15	73
1996	32	14	12	17	75
1997	32	14	12	17	75
1998	31	15	12	17	75
1999	32	14	12	17	75
2000	32	14	12	17	75
2001	32	15	11	17	75
2002	32	14	11	17	74
2003	32	14	11	17	74
2004	32	14	11	17	74
2005	32	14	11	17	74
2006	32	14	11	17	74
2007	32	14	11	17	74
2008	32	13	11	16	72
Total	887	369	268	312	1,836

furnish estimates of their uranium production during each of the next 5 years. Information from these requests is used to blend the prior year's actual production with the producers' 5-year plans and with future production levels that could be attained under an assumed set of conditions. The individual producer's 5-year plans are not merely totaled and inserted as a portion of the transition period, but each of the company's plans is reviewed and may be increased or decreased in recognition of new developments and the fact that there is a gradual transition from actual operations to a "could" production capability.

OBSERVATIONS CONCERNING THE $50 PER POUND PRODUCTION CAPABILITY ESTIMATE

1. The $50 per pound U_3O_8, or less, forward cost level of uranium resources on which the production capability was based would require substantially higher prices for uranium than are currently being paid to warrant the uranium industry producing at the levels that have been indicated "could" be produced under the assumed conditions.

2. Level of demand for domestically produced U_3O_8 in concentrate would have to be com-

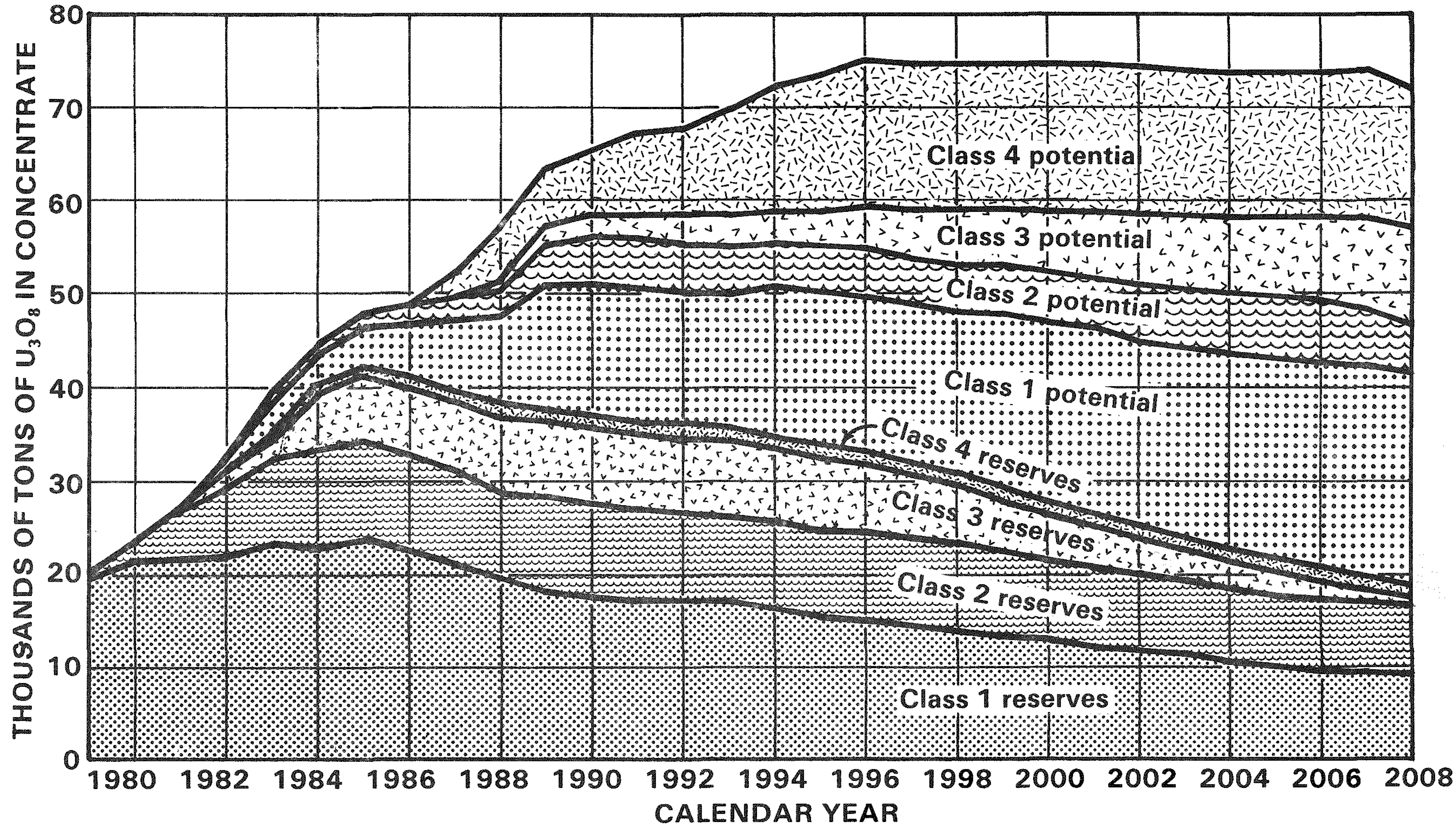

FIGURE 4. *Estimated $50/lb "could" production capability—annual by resource type*

TABLE 6. *Estimated "could" production capability as of 1/1/79—U_3O_8 in concentrate at $50/lb—by resource category*

	Production, Tons U_3O_8 in Concentrate, (x 10^3)			
	Reserves	Probable Potential	Byproduct	Total
Class 1	438	393	56	887
Class 2	191	118	60	369
Class 3	151	117	—	268
Class 4	6	285	21	312
Total	786	913	137	1,836

mensurate with production and annual differences in imports and exports as well as changes in producer, consumer, and government inventories.

3. Exploration, development, construction, and production constraints due to environmental and regulatory permitting and licensing would have to remain at the level which existed at the time of the study.

4. The degree of uncertainty of production from the various classes of production centers increases as one proceeds from Class 1 through Class 4. Class 4 centers are based essentially on probable potential resources, which means that nearly all the "ore" still needs to be found and developed, adding considerably to the uncertainties.

COMPARISON OF 1979 PRODUCTION CAPABILITY ESTIMATE WITH ESTIMATES MADE IN 1977 AND 1978

Comparisons of the $50 per pound "could" production capability estimate made in 1979 and the $30 per pound estimates made in 1977 and 1978 are shown on figure 12. The $50 per pound "could" production capability estimate is less than the 1977 estimate for each year through 1981 but greater from 1982 through 2008 with differences reaching about 13,000 tons U_3O_8 in the mid 1990s. These increases, of course, result mainly because there are more $50 resources than there are $30 resources. As indicated previously, more ore would need to be mined and milled not only because of higher U_3O_8 production rates but also because of lower average grades of the $50 resources.

The 1978 $30 per pound production capability estimate included an experiment in statistical procedures to test uncertainty in such estimates. Low, mid, and high estimates of production of U_3O_8 in concentrate were made from each source of ore for each year and then used to define a probability density function. The sums of the means, sums of the variances, and sums of the third moments were used to define a cumulative distrubition function from which the upper and lower bounds of the 90-percent confidence intervals and the mean values were calculated. The production capability estimate for the 1978 mid case is shown on figure 12. Note that the 1978 estimate was for only 10 years. The 1978 estimate did not include estimates of production from Class 4 centers. The 1978 estimate generally falls between the 1977 and 1979 estimates, except for 1986 and 1987 when Class 4 production centers begin to have an impact. The 1978 estimate is closer to the 1977 estimate because the same resource base ($30 per pound) was utilized.

COMPARISON OF DOMESTIC "COULD" PRODUCTION CAPABILITY AND DOMESTIC REQUIREMENTS*

Figure 13 compares the $50 per pound "could" capability with domestic uranium requirements based on DOE's perception of reactor needs under two empirical burnup options for a "mid-case" projection of nuclear power. The "mid-case" nuclear power capacities, shown on figure 14, are based on a 65-percent nominal capacity factor. One burnup option assumes the current once-

*Nuclear power projection and uranium requirements discussed by R. Gene Clark and Andrew Reynolds in their paper entitled "Uranium Market Forecast" presented at the Uranium Industry Seminar, Grand Junction, Colorado, October 1979.

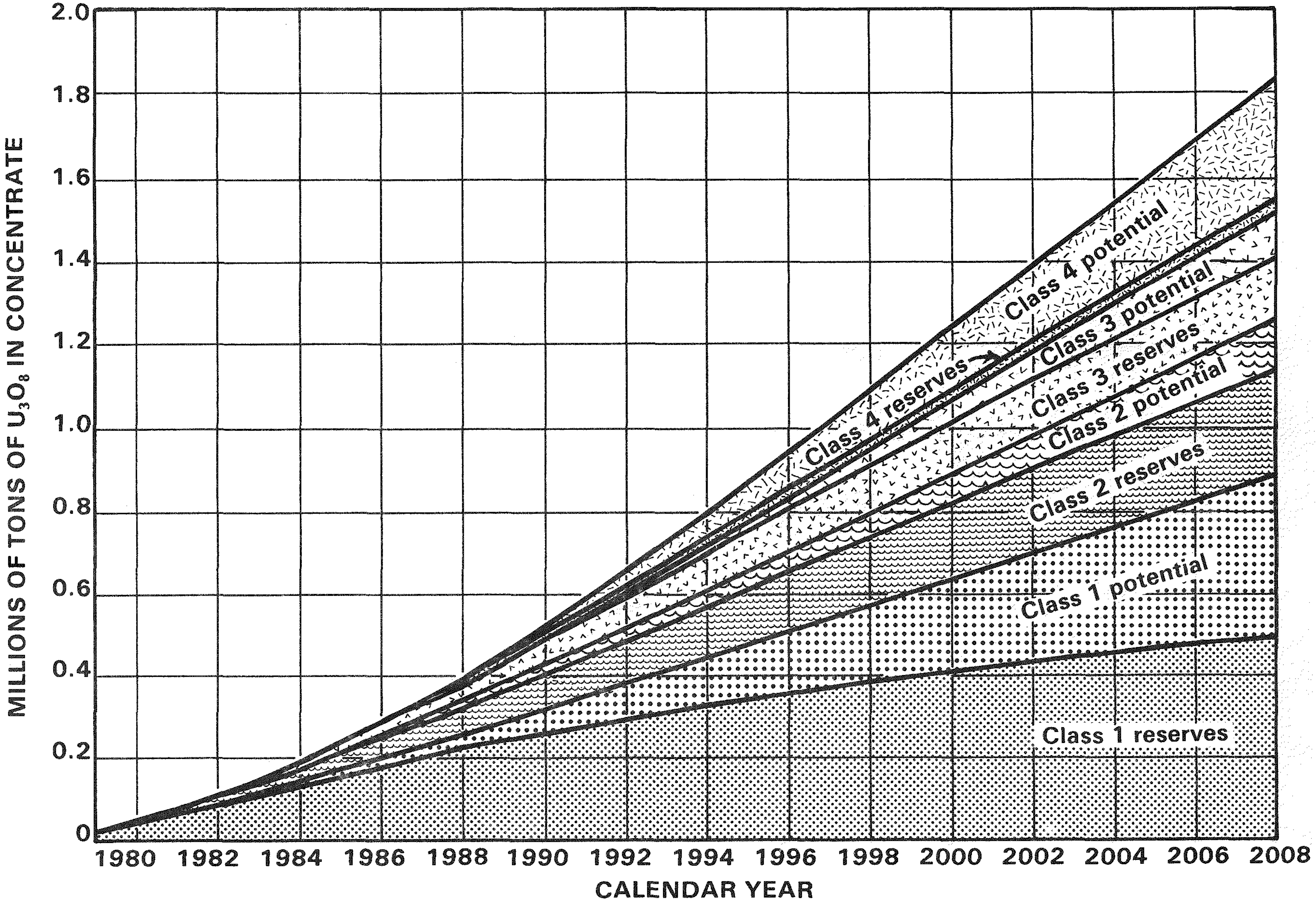

FIGURE 5. *Estimated $50/lb "could" production capability—cumulative by production center class*

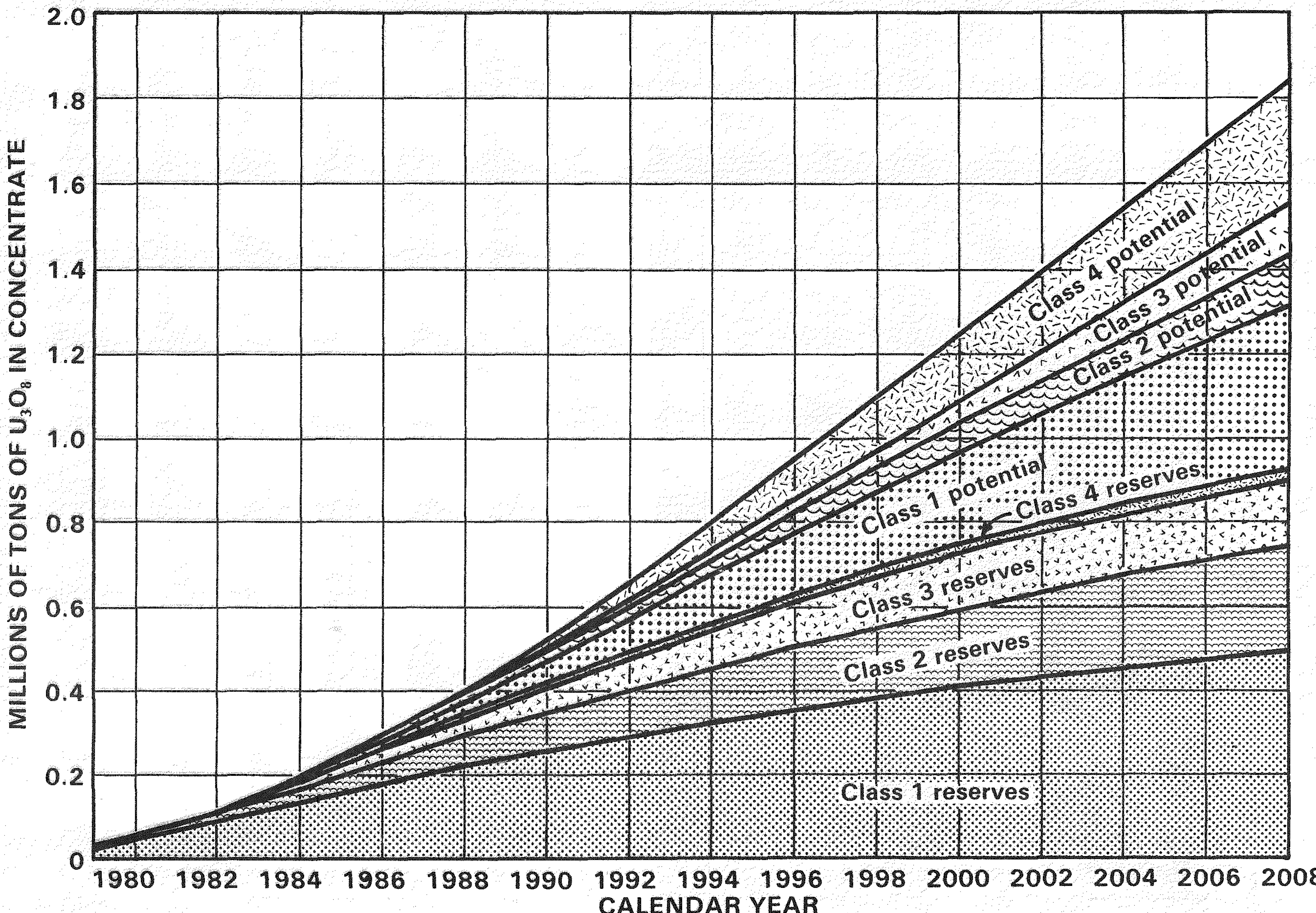

FIGURE 6. *Estimated $50/lb "could" production capability—cumulative by resource type*

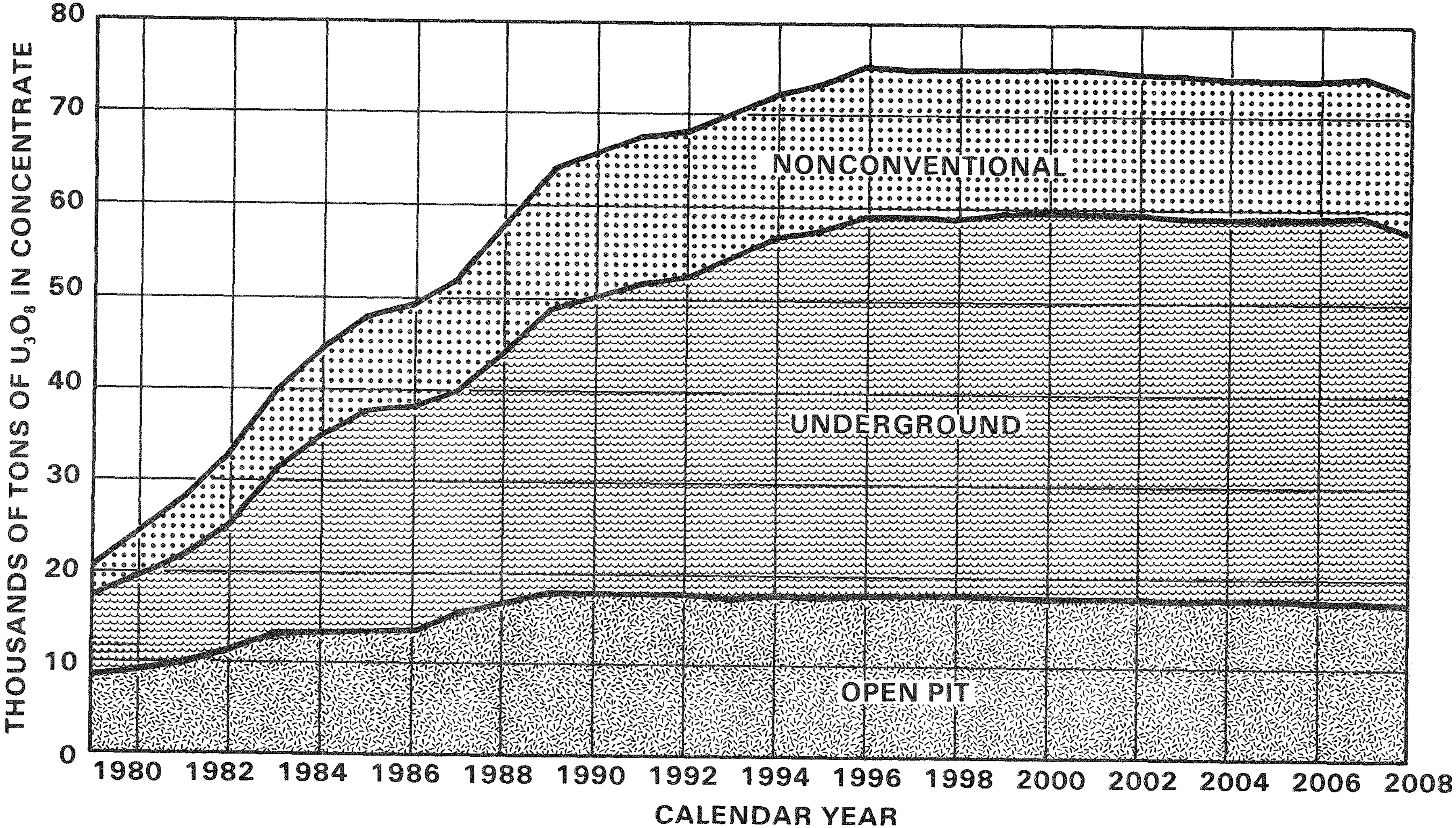

FIGURE 7. *Estimate $50/lb "could" production capability by mining method*

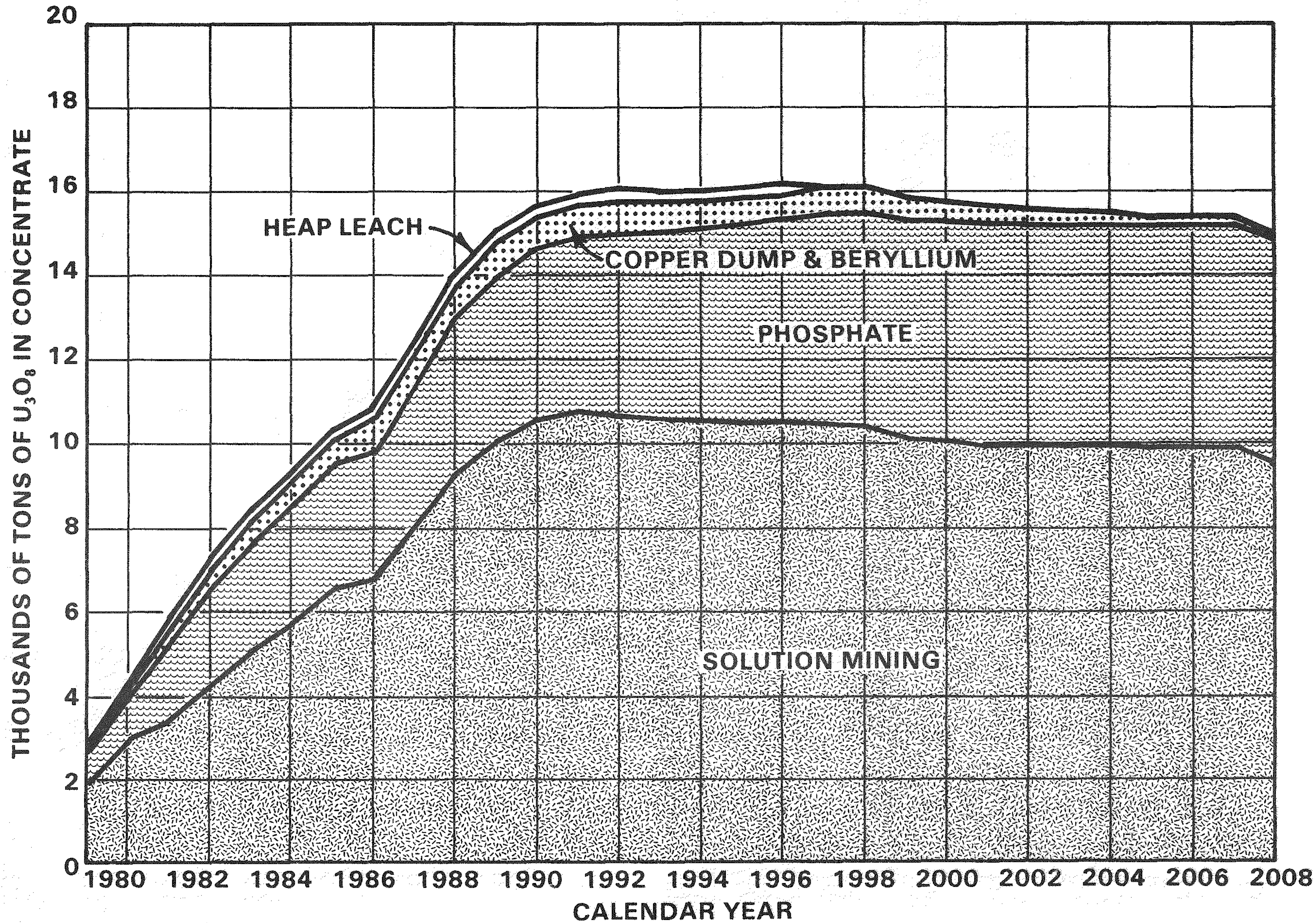

FIGURE 8. *Estimated $50/lb "could" production capability from nonconventional sources*

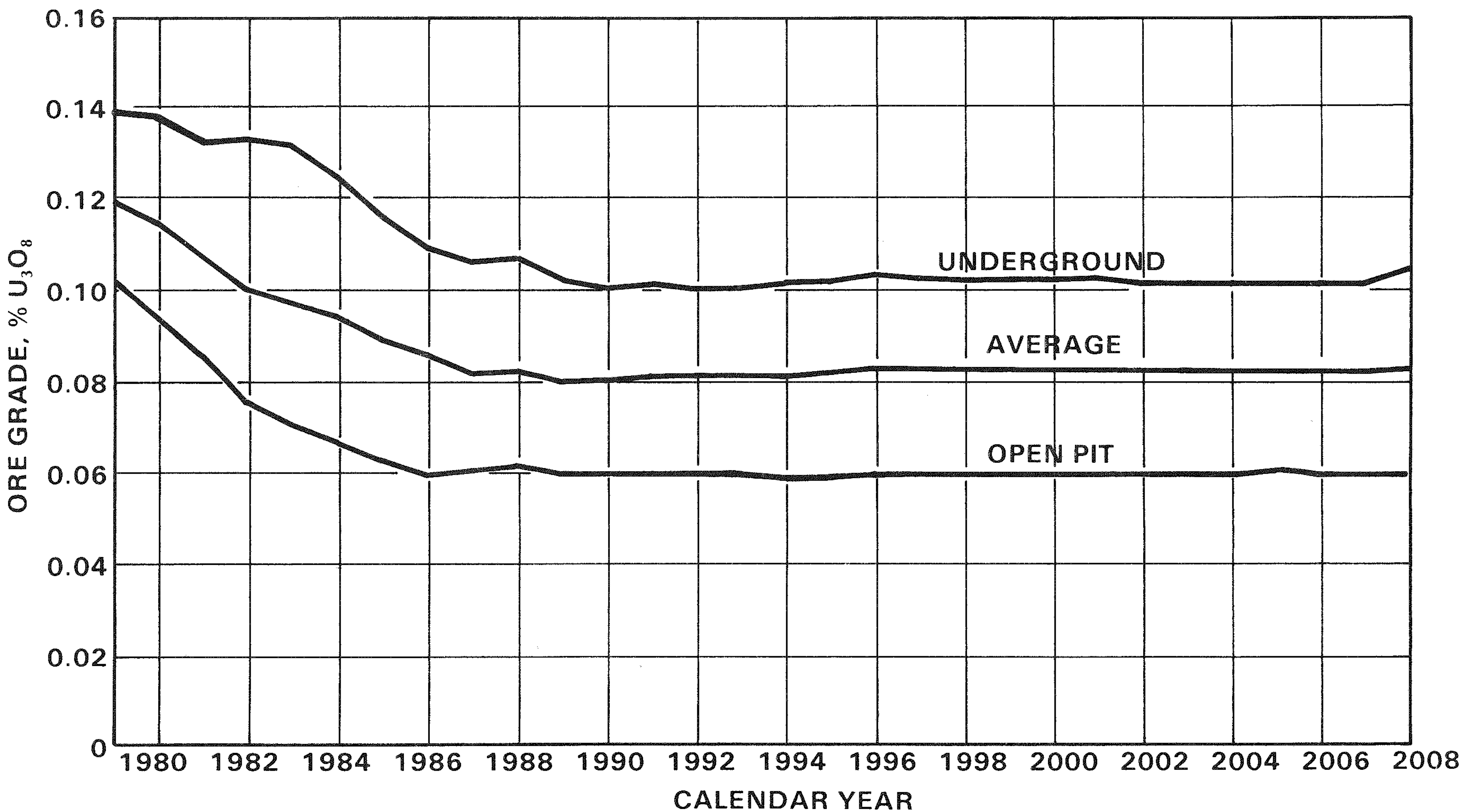

FIGURE 9. *Estimated grade of $50/lb conventional ore mined and milled*

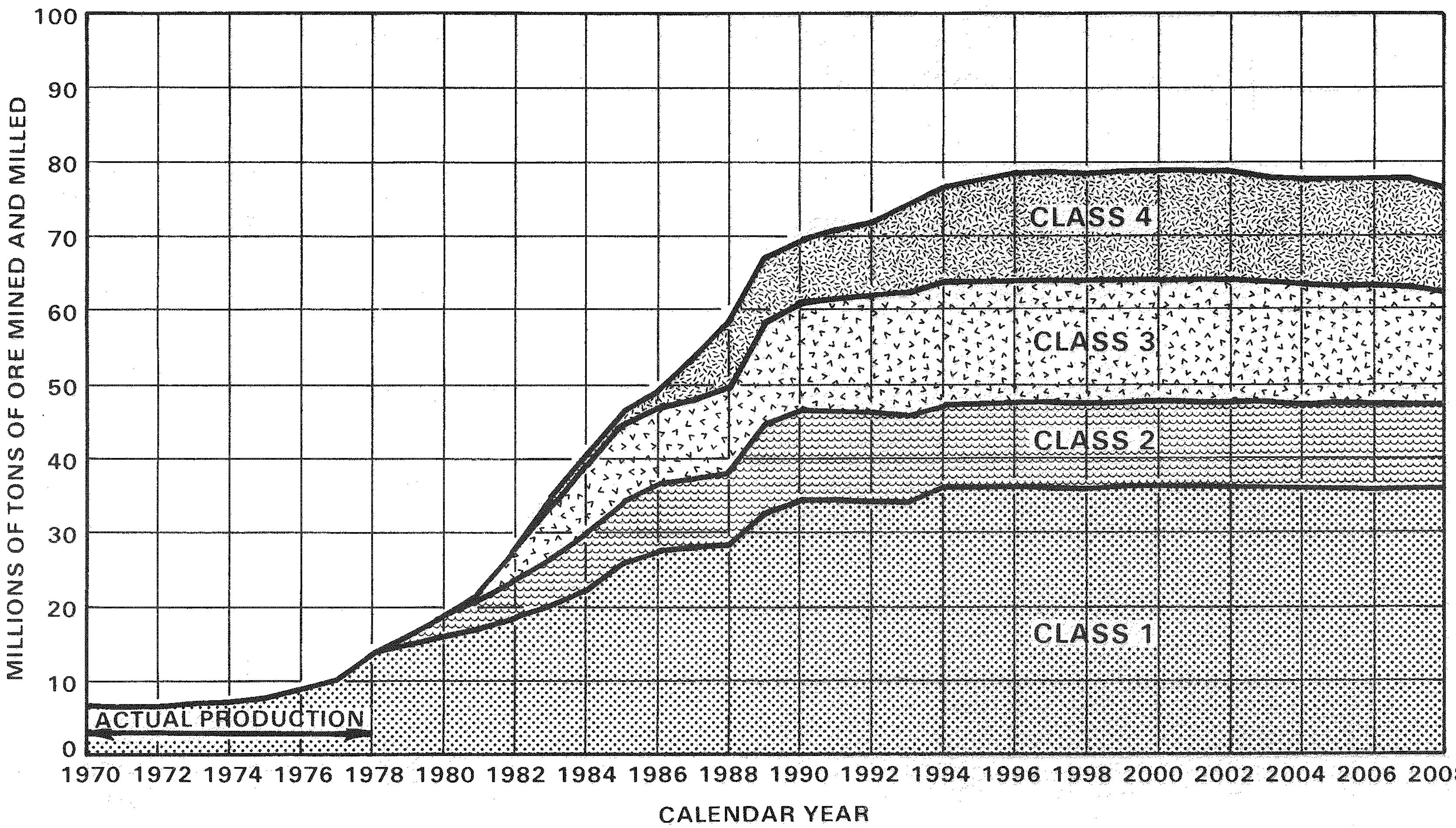

FIGURE 10. *Tons of ore mined and milled—actual 1970 through 1978—estimated $50/lb "could" production capability 1979 through 2008*

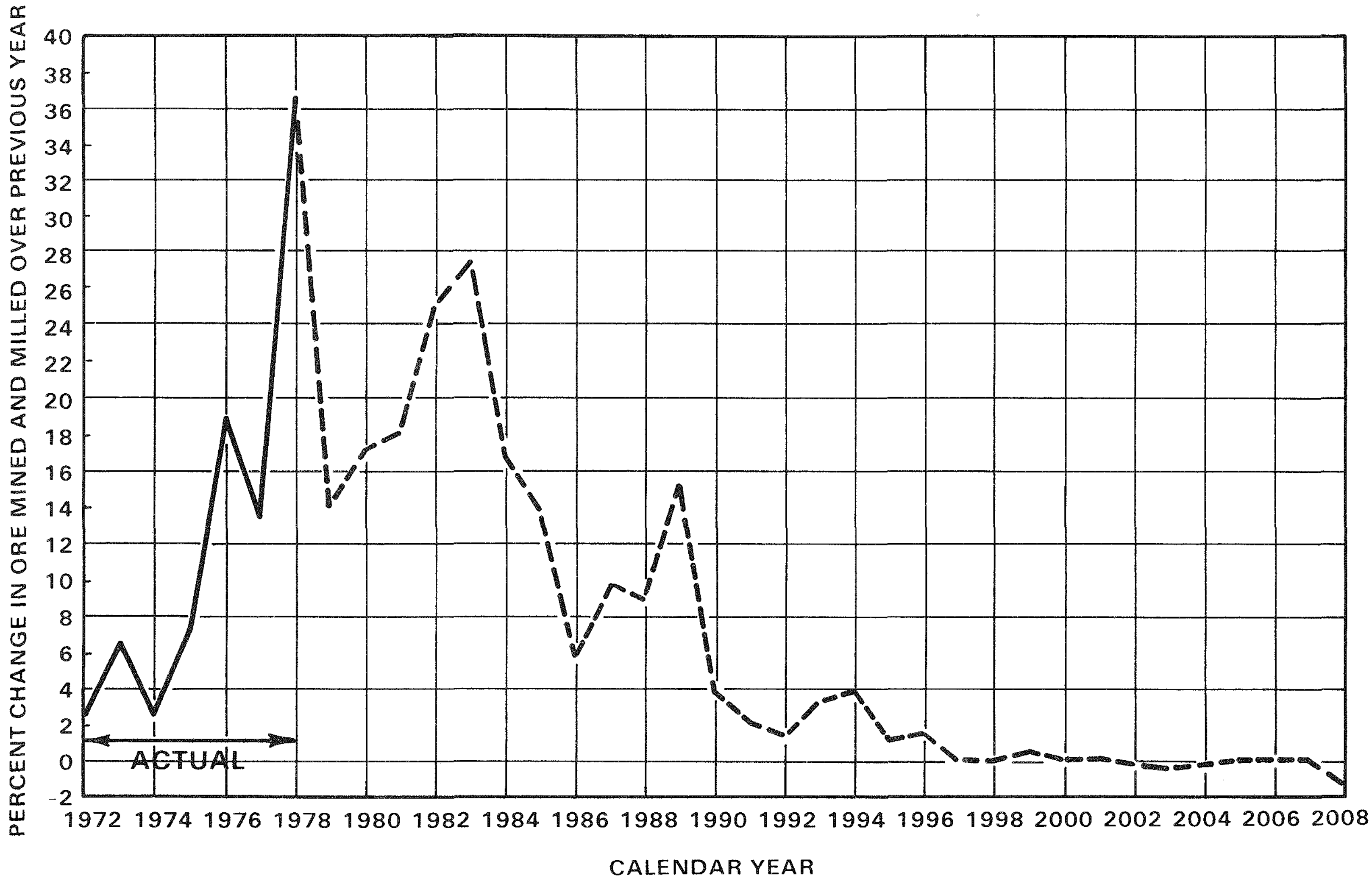

FIGURE 11. *Percent change in tons of ore mined and milled over previous year—actual 1972 through 1978— estimated $50/lb "could" production capability 1979 through 2008*

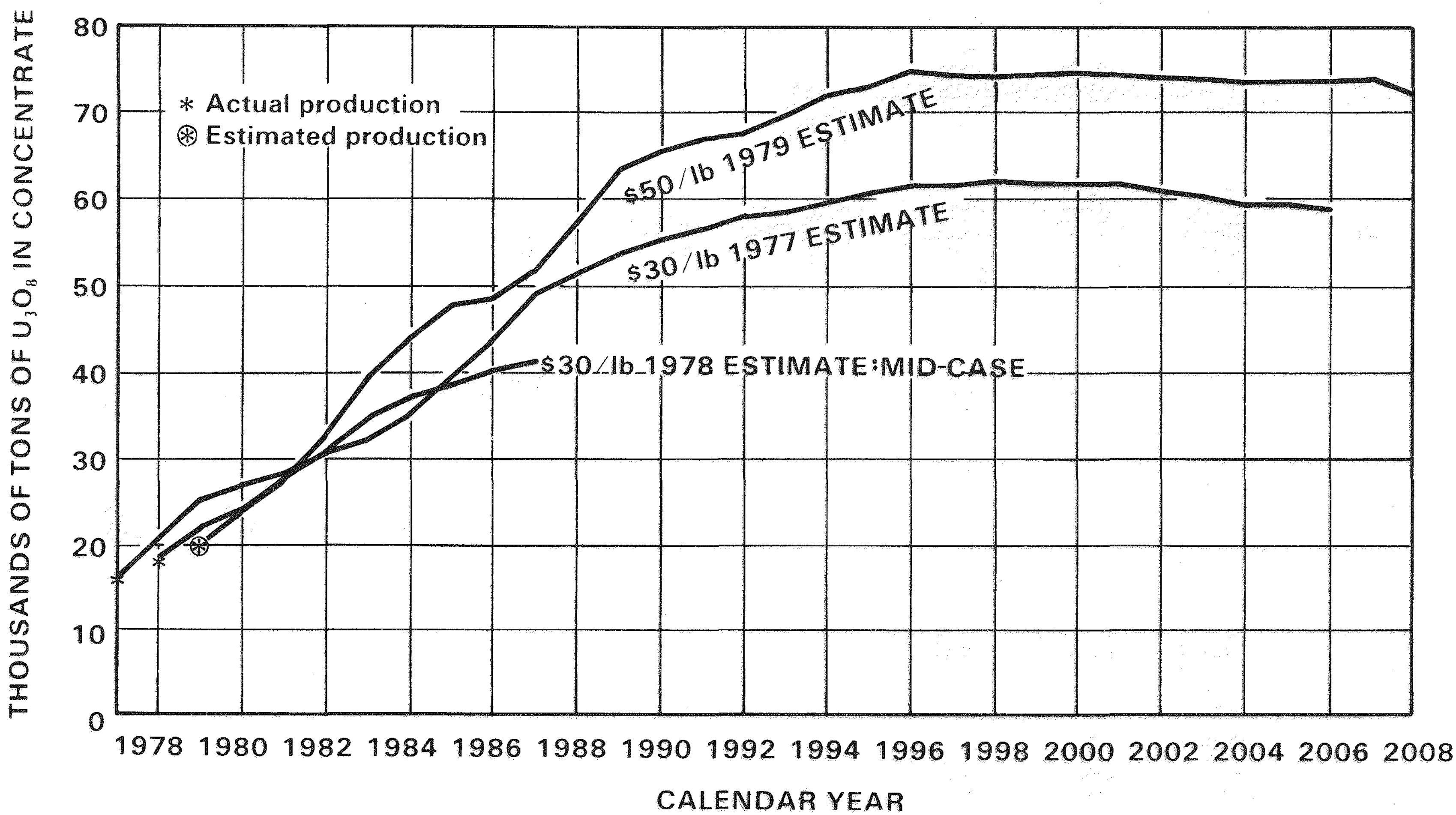

FIGURE 12. *Comparison of production capability estimates made in 1977, 1978, and 1979*

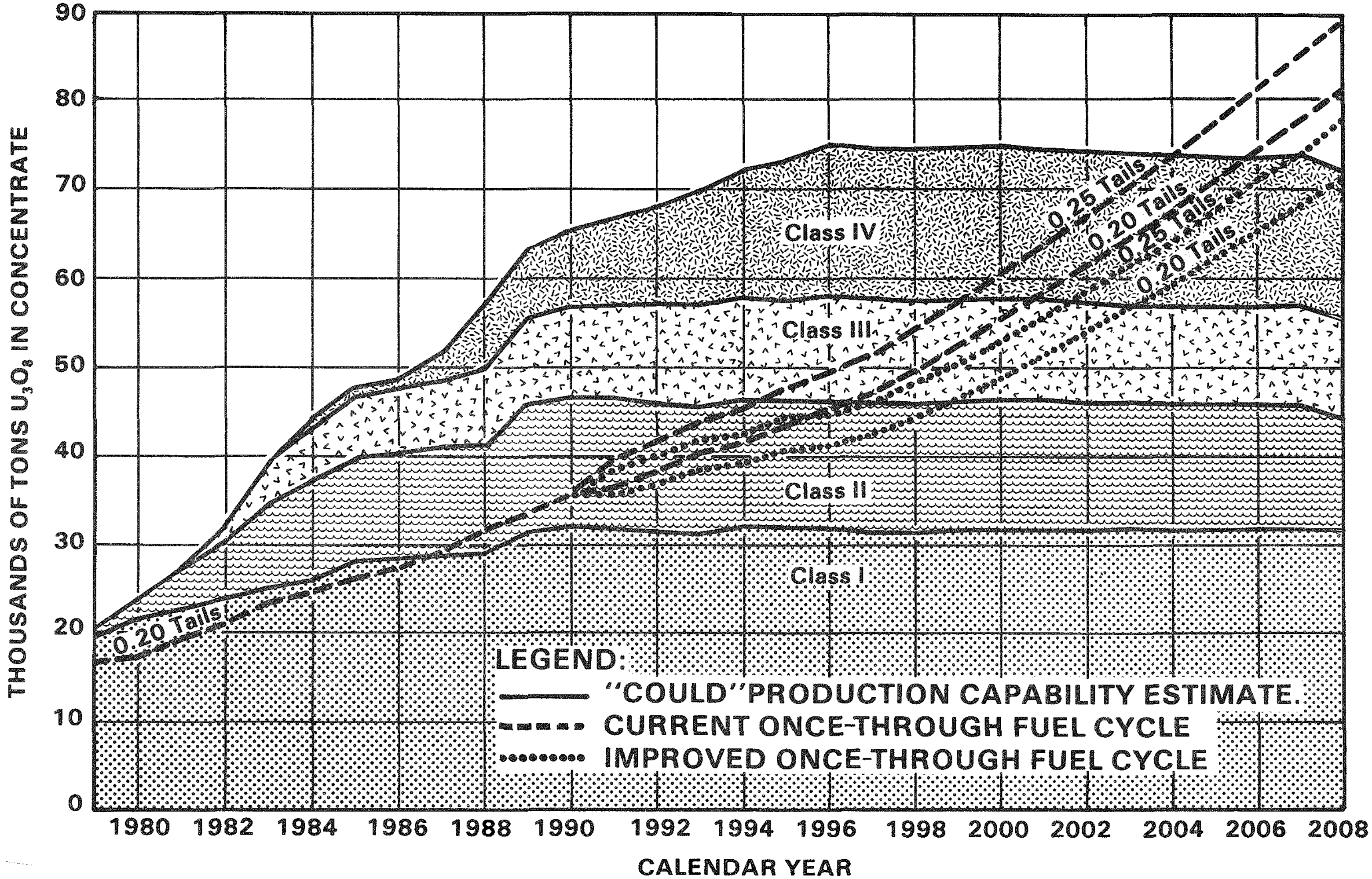

FIGURE 13. *Comparison of $50/lb "could" production capability estimate with requirements*

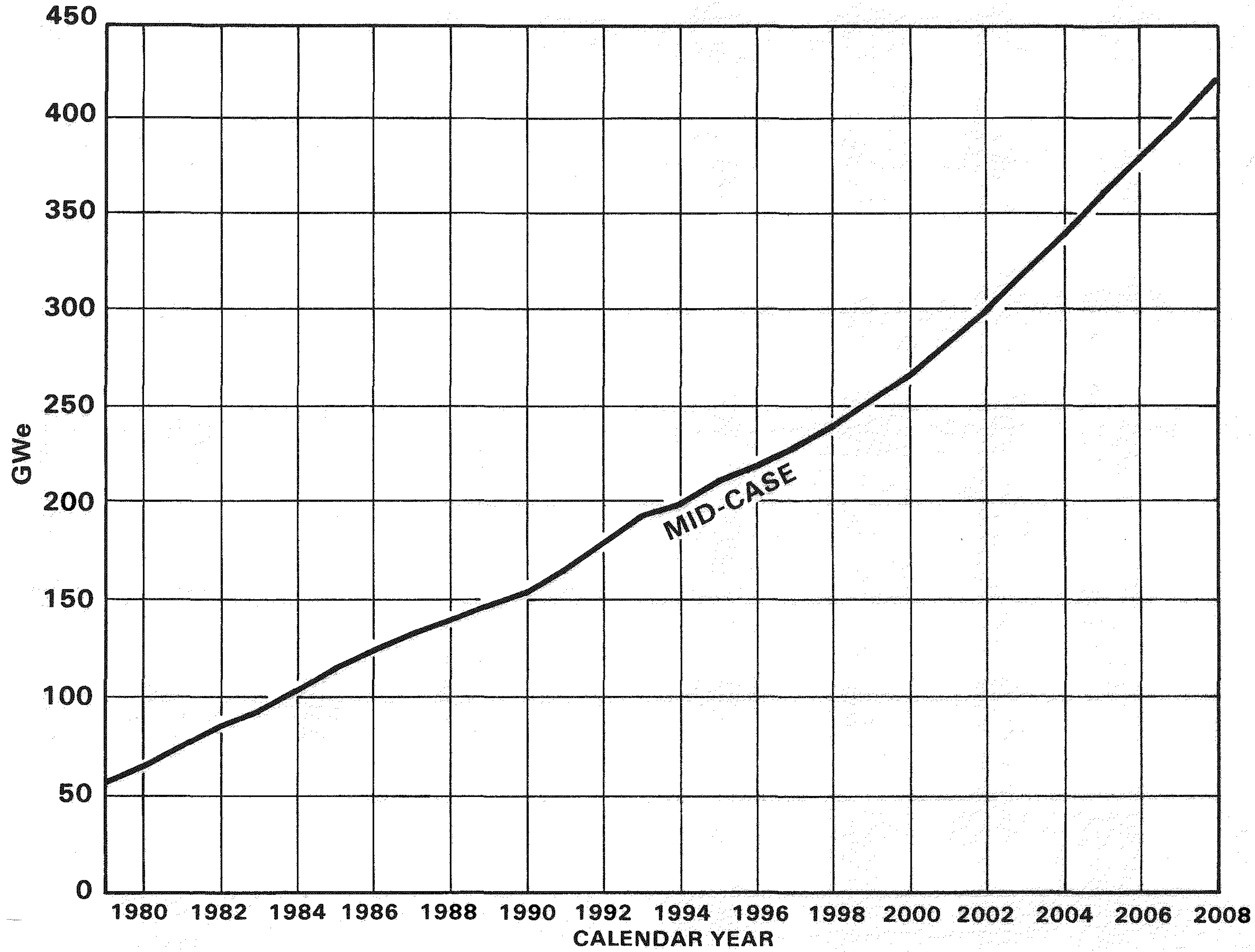

FIGURE 14. *Estimated nuclear power growth*

through fuel cycle, and the other assumes an improved once-through fuel cycle being introduced in 1990 with ten percent of the plants retrofitted each year. The saving in fuel under the improved once-through cycle amounts to about 13 percent in the year 2008. Requirements of U_3O_8 in concentrate are based on 0.20 percent ^{235}U enrichment-plant tails assays through 1990. Requirements under both 0.20- and 0.25-percent tails assays are shown on figure 13 beginning with 1991.

Of course, as mentioned earlier, U.S. "could" production capability estimated as of January 1, 1979, would not be sustained past that date if the uranium industry does not have sufficient incentives. The primary incentive is the level of total demand for uranium concentrate. If industry's perception of total U.S. uranium demand is comparable to the "requirements" shown on figure 13, then the "could" production capability will rapidly deteriorate.

UNIT COST PROFILE—1977 30-YEAR ESTIMATE

The Grand Junction Office not only makes production capability estimates, but it also estimates operating and forward capital costs for those production capability estimates. These cost estimates are made separately for each production center taking into account the differing situations that prevail. Such cost estimates are now being made for the $50 per pound "could" production capability study.

At the 1977 Uranium Industry Seminar, we reported on the uranium industry's capability to produce U_3O_8 in concentrate over the 30-year period from 1977 through 2006 from $30 per pound per pound resources (as of January 1, 1977) but had not estimated the operating and forward capital costs as of that time. At the 1978 Uranium Industry Seminar, costs for the 1977 estimate were presented in the form of unit cost ranges for the various cost elements. These ranges were shown by geographic area as well as for the entire United States.

Because of interest shown by various segments of the industry, we have arranged the unit forward costs from the 1977 study in ascending order by production center. The result of this arrangement is shown in figure 15. The 1.4 million tons U_3O_8 in concentrate that would be produced under the 1977 "could" production study represents production only from economic production centers. Economic production centers are defined by the "economic analysis" step of the methodology illustrated by figure 16. Our policy is to include in the summation only those production centers whose estimated average forward costs are no higher than 110 perent of the "maximum" cost within the cost category being studied. In this case, only those centers with average costs no higher than $33.33 per pound of U_3O_8 in concentration were included.

URANIUM SUPPLY ANALYSIS SYSTEM

A sophisticated computerized system is needed to help provide, on a timely basis, government planners and officials with information pertaining to relationships between uranium resources, production capabilities, production costs, prices, and uranium requirements. A subcontract to develop such a system was awarded in February 1979 to Dames & Moore with significant participation by International Energy Associates, Ltd. and Colorado School of Mines. The project is on schedule for completion by May 15, 1980.

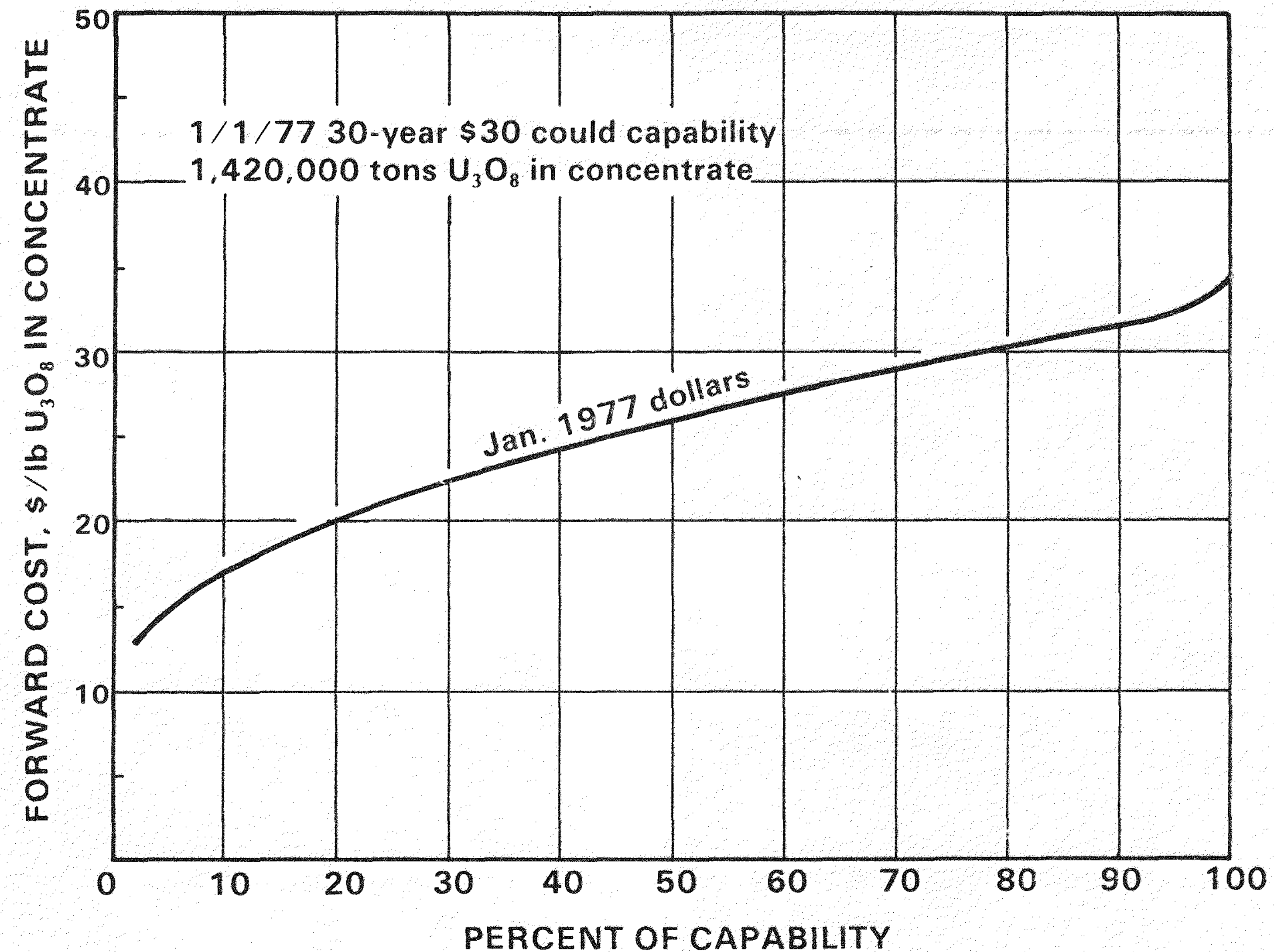

FIGURE 15. *Forward cost profile of all production center classes*

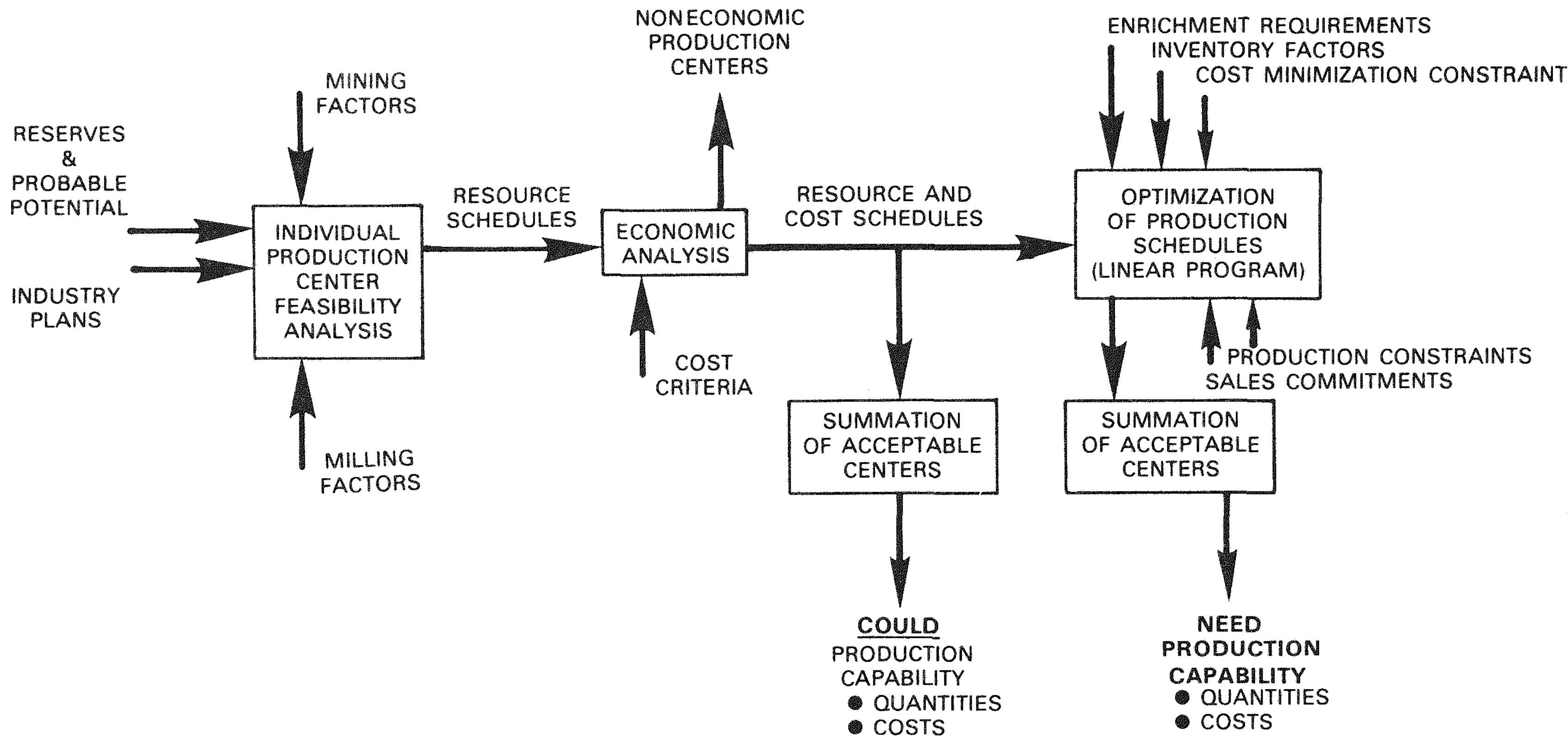

FIGURE 16. *Production capability methodology*

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