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SUPPLEMENTAL TESTIMONY OF JOHN A. PATTERSON
U. S. ENERGY RESEARCH AND DEVELOPMENT ADMINISTRATION
ON
URANIUM RESOURCES AVAILABILITY

7/11/77

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Uranium-Resources Availability*

This testimony reviews information available from the Energy Research and Development Administration (ERDA) on the domestic uranium-resource situation and the outlook for development of additional domestic supplies, availability of foreign uranium, and the relationship of uranium supply to planned nuclear generating capacity. Analysis of uranium resources and their availability has been carried out by the government since the late 1940s. The work was done for many years by the Atomic Energy Commission, and was made the responsibility of ERDA when the agency was created in early 1975.

U.S. Resource Position

To establish some basic concepts, a review of resource concepts and nomenclature [National Uranium-Resource Evaluation (NURE)] would be worthwhile. Figure 1 is a chart of resource categories based on varying geologic knowledge and on varying economic availability. Resources designated as ore reserves have the highest assurance regarding their magnitude and economic availability. Estimates of reserves are based on detailed sampling data, primarily from gamma-ray logs of drill holes. ERDA obtains basic data from industry from its exploration effort and estimates the reserves in individual deposits. In estimating ore reserves, detailed studies of feasible mining, transportation, and milling techniques and costs are made. Consistent engineering, geologic, and economic criteria are employed. The methods used are the result of over 25 years effort in uranium-resource evaluation.

* In this section, some values are expressed in conventional English units to retain the convenience of easy comparison of round numbers; e.g., uranium chemical prices and weights.

CUTOFF COST	ORE RESERVES	NURE POTENTIAL			ULTIMATE POTENTIAL
		PROBABLE	POSSIBLE	SPECULATIVE	
		(Known Districts- Identified Trends)	(Productive Provinces, in Pro- ductive Formations)	(New Provinces or New Formations)	
\$8					
\$10					
\$15					
\$30					
HIGHER COST					

DECREASING KNOWLEDGE AND ASSURANCE
→

Fig. 1. ERDA Uranium-Resource Categories.. (\$10/lb = \$22/kg)

Resources that do not meet the stringent requirements of reserves are classed as potential resources. For its study of resources, ERDA subdivides potential resources into three categories: probable, possible, and speculative.¹ Probable resources are those contained within favorable trends, largely delineated by drilling, within productive uranium districts (i.e., those having more than 10 tons U_3O_8 production and reserves). Quantitative estimates of potential resources are made by considering the extent of the identified favorable areas and by comparing certain geologic characteristics with those associated with known ore deposits. Possible potential resources are outside of identified mineral trends but are in geologic provinces and formations that have been productive. Speculative resources are those estimated to occur in formations or geologic provinces that have not been productive but which, based on the evaluation of available geologic data, are considered to be favorable for the occurrence of uranium deposits.

The reliability of the estimates of potential uranium resources differs for each of the three potential classes. The reliability of probable potential estimates is greatest in view of the more complete information resulting from the extensive exploration and development in the major uranium districts. It is least for speculative potential for areas with no significant uranium deposits, for which favorability is determined from available knowledge of the characteristics of the geologic environment.

Because any evaluation of resources is dependent on the availability of information, the estimates themselves are, to a large degree, a score card on the state of development of information. Thus, appraisal of United States uranium resources is heavily dependent on the completeness of exploration efforts and the availability of subsurface geologic data. Because the geology of the United States as it relates to mineral deposits can never be completely known in detail, it will not be possible to produce a truly complete appraisal of domestic uranium resources. However, given the nature and current status of ERDA estimates as far as an overall appraisal of the United States is concerned, it is more likely that the total resources eventually will produce larger than present estimates than that they will be less. The key question may be the timeliness with which resources are identified, developed, and produced.

Conceptually, a resource, whether uranium or other mineral commodity, would initially be in the potential category. Development of additional data and clarification of production techniques and economics is required until the point is reached that specific ore deposits are delineated and understood to a degree that they can be categorized as reserves.

We can expect that there will be a dynamic balance between anticipated markets and prices and the extent to which exploration and reserve delineation will be done. There is no economic incentive for industry to expand reserves if the additional uranium will not be needed for many years ahead, especially if the long-term market outlook is uncertain. This has been so for uranium. The mining companies are concentrating on markets for the next 5 to 15 years. The utilities and government are concerned with the outlook for the next 30 to 40 years. Conversion of the presently estimated potential resources into ore reserves will take many years and will cost several billion dollars. It would be difficult economically to justify accelerating such an effort to delineate ore-reserve levels equal to lifetime requirements of all planned reactors covering some 30-40 years in the future, simply to satisfy planners.

Supply assurance through continued timely additions to reserves and maintenance of a resource base adequate to support production demands, coupled with carefully developed information on potential resources, is considered to be adequate and a more realistic and economic approach. The conversion of potential resources to ore reserves and expansion of production facilities can be accomplished when needed as markets expand and production is needed.

The vertical dimension in Figure 1 relates to the impact of increasing production costs on resource availability. Higher prices are needed to produce ores of lower quality and those with more difficult mining or milling characteristics. Such reserves, though well delineated, are not available if prices are too low.

The domestic uranium industry has, over most of its lifetime, been concerned with discovery and production of uranium at costs in the \$8-10/lb range or less.

Average prices for uranium deliveries in 1975 were reported to be \$10.50 per pound of U_3O_8 . Prices for 1976 deliveries were \$16.10 per pound.² In view of the economic acceptability of higher-cost uranium in reactors, resource estimates by ERDA in recent years have included resources that would be available at \$15 and \$30 production cutoff costs. An initial estimate of \$50 resources has been made as of January 1, 1977.³ Because less attention has been paid to higher cost resources, they are not as fully delineated or as well understood as the lower cost resources.

At cost levels above \$50/lb, there has been little effort at appraisal of resources or in exploration. Therefore, these resources are poorly known at present and quantitative estimates are not possible (with the exception of the Chattanooga shale to be discussed later). Such resources are known to exist, and efforts are under way to appraise them.

In Table 1 are tabulated ERDA estimates of domestic uranium resources following the conceptual arrangement of Figure 1. These estimates reflect the results of the preliminary phase of the NURE program. The resource estimates totaled 3.5 million tons up to a production cost of \$30, and 4.3 million tons at \$50. Of this total, 840,000 tons are in the ore-reserve category. An additional estimated 140,000 tons are attributed to byproduct material through the year 2000.

In this evaluation program, the nation has been divided into study areas as shown in Figure 2. For comparison, the major known uranium areas in the U.S., such as the Colorado Plateau, Wyoming Basins, and Texas Gulf Coastal Plain, are shown in Figure 3.

Table 1. U.S. Uranium Resources (tons U_3O_8)Thousands of tons U_3O_8

$\$/lb U_3O_8$ Cost Category	Reserves	Potential			Total
		Probable	Possible	Speculative	
\$10	250	275	115	100	740
\$10-15 increment	<u>160</u>	<u>310</u>	<u>375</u>	<u>90</u>	<u>935</u>
\$15	410	585	490	190	1,675
\$15-30 increment	<u>270</u>	<u>505</u>	<u>630</u>	<u>290</u>	<u>1,695</u>
\$30	680	1,090	1,120	480	3,370
\$30-50 increment	<u>160</u>	<u>280</u>	<u>300</u>	<u>60</u>	<u>800</u>
\$50	840	1,370	1,420	540	4,170
	<u>140*</u>				<u>140</u>
	980	1,370	1,420	540	4,310

* Byproduct of phosphates & copper production

The geographic distribution of estimated potential resources is shown in Figure 4.

Only limited data are available for much of the country and estimates for these areas will be largely in the speculative category, or unassessed, for some time. The preliminary phase of the NURE program has identified additional areas with geologic characteristics favorable for the occurrence of uranium deposits, but for which data were inadequate for evaluation of potential resources. The location of areas with estimated potential resources and other favorable areas is shown in Figure 5. The NURE program will develop considerable additional basic information in the next several years that will lead to a more comprehensive, in-depth evaluation of the U.S. long-term resource outlook.

Fig. 2 National Uranium-Resource Evaluation (NIRE) Regions.

Fig. 3 Principal U. S. Uranium Areas.

Fig. 4 Potential Uranium Resources by Region (\$30/lb U_3O_8).
(100,000 tons = 90,000 tonnes, \$30/lb = \$66/kg)

Fig. 5 National Uranium-Resource Evaluation--Preliminary Potential and Favorable Areas.

Attainable Production Levels and Reactor Capacity

The domestic industry currently has a production capacity of around 16,000 tons U_3O_8 per year. Plans have been reported to expand capacity to 27,000 tons/year by 1979. Industry plans to spend \$535 million in 1977 and \$389 million in 1978 on new mining and milling capacity, compared with \$255 million spent in 1976. Study of attainable production capability from currently estimated \$15 U.S. ore reserves and probable potential resources indicates that production levels of 60,000 tons U_3O_8 per year can be achieved with aggressive resource development and exploitation. Although the level may be achievable by use of domestic \$15 ore reserves and probable resources alone, development and utilization of \$15 possible and speculative categories and use of \$30 ore reserves and potential resources would provide added assurance that the levels could be attained and sustained. Considering that some imported uranium will add to supplies, it is considered realistic to plan on the basis that a 60,000-tons/year supply is achievable from currently estimated resources. Such a level could be reached by the early 1990s.

The level of nuclear generating capacity supportable with this amount of uranium, as shown in Figure 6, will vary with enrichment tails assay and recycle assumptions. Without recycle of uranium or plutonium and with a 0.30% U-235 enrichment tails assay, about 260,000 MWe could be supported. Without recycle, and at 0.20% tails, 310,000 MWe could be supported. As shown in Figure 6, all the levels of supportable capacity are well above the 236,000 MWe of capacity in operation (46,000 MWe), under construction (95,000 MWe), on order (68,000 MWe), and announced (27,000 MWe) as of January 1, 1977. Thus, presently estimated

Fig. 6. Nuclear-Reactor Capacity (GWe).
(60,000 tons = 55,000 tonnes)

resources can provide adequate uranium supplies for a sizable expansion to U.S. nuclear generating capacity.

The cumulative lifetime (30 years) uranium requirements for all these reactor cases would be less than the 1.9 million tons in \$30 (or the 2.3 million tons at \$50) ore reserves, byproduct, and probable potential resources. Evaluation of long-term fuel commitments on the basis of ore reserves and probable

potential resources is considered a prudent course for planning. The lifetime commitment would be less than half of currently estimated \$50 domestic resources, including the possible and speculative categories.

Uranium Resource Recovery

In regard to the availability of estimated uranium resources, considering recoveries in mining and ore processing, estimates of U.S. uranium resources represent the quantity of uranium estimated to be minable expressed as tons U_3O_8 of ore in the ground. These estimates are a reflection of the information available to ERDA at the time of the estimate; thus, they are dependent on the extent of exploration work that has been performed. In view of the considerations involved in preparing the resource estimates and the uranium-resource outlook, no adjustment for losses is warranted.

U.S. mining practice results in recovery of high percentages of the uranium contained in a deposit. ERDA resource-estimation procedures consider the capabilities and requirements of mining systems in use so that the estimates are a realistic appraisal of what is minable. Because deposits frequently are not fully delineated before they are developed, it is not unusual for considerably more uranium to be recovered from deposits than were included in ore reserves before such deposits were put into production. Mining-company practice seeks to recover as much of the contained mineral content as possible before abandoning a mine. Higher uranium prices provide a strong incentive for such practice. In the processing of uranium ores, recoveries generally are over 90%. In 1975 mill recovery averaged about 93.5%. Higher recoveries are usually possible if economically justified.

Also, there are additional resources which will be available beyond the currently estimated \$30 reserves, byproduct, and probable potential resources. The life-time uranium needs of the sustainable level of capacity noted would require only about half of the \$30 resources including possible and speculative potential resource categories now estimated for the U.S. With development of additional information on U.S. resources, it is considered likely that the future estimates of resources in the U.S. will be even larger than now estimated. The NURE program and industry exploration will expand the data available on U.S. resources, leading to a more complete evaluation. Additional uranium supplies will be available from foreign sources and, if needed, through utilization of higher-than-\$30-cost resources.

In view of these factors, it is not considered meaningful to make adjustments to reserve and resource estimates for possible future losses from mining and milling.

Prospects for Expanding U.S. Supply

The long-range-supply outlook (through the rest of the century and beyond) will be largely influenced by the extent to which the present resource position is modified in the decades ahead. There are three principal means by which the supply position can change. First, through the identification of additional resources in the less-than-\$30/lb category; second, through utilization of already-identified higher-cost resources; and third, through utilization of foreign uranium supplies. These means will be examined separately.

Domestic Low-Cost Resources

An evaluation of the potential for developing additional domestic low-cost uranium resources beyond those now estimated involves the following considerations:

1. Experience generally has been that mineral resources ultimately prove larger than can be estimated at any time. We are limited by what occurs in nature but also, and perhaps more so, by the degree of our knowledge. Development of information on unknown or poorly explored areas is likely to increase the estimate of resources. As previously noted, there is no complete assessment of the U.S. uranium position. The NURE effort is scheduled to produce a nationwide in-depth assessment in 1981.

Comparing the U.S. uranium-resource position ten years ago with today's can illustrate the point. In 1966 \$10 ore reserves were estimated to be 195,000 tons U_3O_8 . Potential resources then estimated, which correspond to the current "probable" potential category plus a portion of the "possible" category, were 325,000 tons U_3O_8 . Since then, 134,000 tons of U_3O_8 have been produced. In 1976 the estimates were 270,000 tons of reserves and 440,000 tons of probable potential. Thus, in the ten years, over 320,000 tons were added to these categories of resources. During the period, the value of the dollar has declined to about 60% of its 1966 value. Because inflation increases costs, moving some material to higher-cost categories, the 1976 resource estimates would have been higher measured in 1966 dollars.

2. Expansion of resources will depend on the level of effort expended. Increased exploration activity can be expected to improve the resource position. Exploration success per unit of effort has been less in recent years, but inflation has exaggerated the reduction because increasingly higher grade ores must be found at a given cost to offset inflation. In addition, there has been a trend toward deeper drilling, which increases the effort required. Exploration results in 1975 and 1976 show improved discovery rates.

Industry-investment activities will be influenced by nuclear-power growth and acceptance, uranium demand, and price movements. As is the case with other raw-material commodities, increasing demands and higher prices should lead to increased efforts by industry to expand supplies.

3. Known U.S. uranium resources are in a few comparatively small areas as shown in Figure 3. The comparatively small geographic areas of the mining districts within these areas suggest that significant undiscovered districts can be overlooked.
4. Domestic uranium resources in sandstone deposits make up over 95% of known U.S. low-cost resources. The bulk of resources in other parts of the world are in other types of geologic environments. A listing of significant types of uranium deposits is shown in Table 2. The possibility exists for identification of additional types of deposits in the U.S.

Table 2. Uranium Deposits

Type	Average Deposit Grades (ppm U_3O_8)	Size Range Tons U_3O_8	United States	Foreign
Massive vein-like	3,000 to 25,000	10,000 to 250,000		Saskatchewan, Canada; Alligator River, Australia
Vein	1,000 to 25,000	1,000 to 40,000	Colorado, Washington	Great Bear Lake, Canada; Shinkolobwe, Zaire; France
Sandstone	500 to 5,000	100 to 50,000	Colorado Plateau Wyoming, Texas	Niger, Gabon, Argentina
Calcrete	1,000 to 3,000	1,000 to 50,000		Yeelirrie, Australia
Quartz-pebble conglomerate	200 to 1,500	10,000 to 200,000		Elliot Lake, Canada; Witwatersrand, South Africa
Alaskite	300 to 400	75,000 to 150,000		Rossing, South-West Africa
Syenite	100 to 400	10,000 to 50,000		Ilimaussaq, Greenland
Phosphate rock	60 to 200	0.5 to 2.0 million	Florida, Idaho	North Africa
Shale	50 to 300	1 to 5 million	Southeast United States	Ranstad, Sweden

Industry-Exploration Activity

The major responsibility for discovering new uranium deposits needed in the years ahead is with private industry. The footage drilled in search for uranium deposits in the U.S. for the last several years is shown in Figure 7. In the period 1967-69, a sharp increase in exploration occurred. Exploration decreased in the early 1970s due to softening in the uranium market as a consequence of the slippage in uranium demands. In 1973, utilities contracted for 52,000 tons of U_3O_8 ,⁴ a far greater procurement effort than had been previously seen, firming prices and rekindling exploration interest. As a result, exploration began to increase again.

As shown in Figure 7, expenditures for land acquisition, drilling, and related activities reached a peak of about \$59 million in 1969, dropped to \$32 million in 1972, but increased to an all-time high of \$171 million in 1976. Plans to expend \$236 million in 1977 and \$251 million in 1978 have been reported to ERDA. Although expenditures are increasing, the footage drilled per dollar of expenditure has been decreasing because of higher costs and a trend toward deeper drilling.

The results of drilling are shown at the bottom of Figure 7 in terms of annual additions to ore reserves. It should be noted that inflation during this period has been high; therefore, the discovery rate measured in terms of \$8 reserves added in 1975 is not directly comparable to those added in 1969 and 1970. The 1969 \$8 reserves are comparable in 1975-1976 to reserves at a cost of around \$15 per pound. The additions of \$10, \$15, and \$30 reserves in the 1972-1976 period are also shown in Figure 7. The additions to \$30 reserves increased

Fig. 7. U.S. Exploration Activity and Plans. (10^6 ft = 3×10^5 m;
\$10/lb = \$22/kg; 1000 tons = 900 tonnes)

substantially in 1975 even though not all the data from industry were available and a number of additional deposits are known to have been discovered. About 100,000 tons U_3O_8 were added to the \$30 reserve in 1976.

Expenditures for uranium exploration have not been large in comparison to the expenditures in other phases of nuclear power. For example, the cost of a typical large reactor alone (over \$800 million) will be larger than the total

of \$690 million spent in uranium exploration (including land acquisitions, drilling, and related activities) in the entire country over the period 1966 through 1976.

Technology Development

In the past, improved technology has provided a means for expanding available resources of minerals. There have been a number of developments in uranium that are improving the supply situation, and others are likely to be developed in the years ahead. Of current interest is the use of in-situ leaching methods where the extraction of the uranium is accomplished by pumping leach solutions down drill holes, through the ore zone, and back to the surface for treatment. Such plants are operating in Texas, and others are planned.

An additional development is the improved process for recovery of uranium from phosphoric acid. A plant is starting operation in Florida, and several others are planned. If all the phosphoric acid currently produced in the large plants in Florida were treated; about 3000 tons U_3O_8 per year could be recovered. Production may reach this level by the early 1980s, and future increases will follow as phosphoric-acid production expands.

Government Uranium-Resource Activities

In view of the need to better understand the long-range prospects for expanded domestic-uranium supply for reactor-development strategy and planning and to assure adequate uranium supplies to fuel nuclear-power growth, ERDA is carrying out programs to assess domestic resources more completely and to improve technology for discovery, assessment, and production of these resources. The basic elements in the ERDA resource program are illustrated in Figure 8.

Fig. 8. Uranium-Resource Strategy.

Starting in the upper-left corner of the diagram, knowledge about known uranium occurrences will be augmented by gathering and generating new data by use of surface, aerial, subsurface, and remote-sensing techniques. This will allow improved estimates in known areas and identification of other areas where known types and postulated new types of deposits may exist. This will increase knowledge about uranium occurrences in the United States, improve estimates of the resource position, and expand and solidify the base of nuclear-fuel supplies. Information is routinely made available to industry for development of their

exploration and mining programs. Industry efforts will generate additional data that will also be used by ERDA in continuing resource studies. An important part of this strategy is research and development to improve the technology involved in uranium discovery, assessment, mining, and milling. ERDA uranium-raw-materials budgets to carry out this program are increasing. In FY 1976, expenditures were about \$14 million. In fiscal year 1977, \$27 million will be spent.

Two activities underway to generate new data systematically are the aerial radiometric reconnaissance program and the national hydrogeochemical survey. Features of the airborne program are highlighted in Table 3. This program will involve some 1,400,000 line kilometers (870,000 line miles) of aerial surveys flown on an average line spacing of eight kilometers (five miles) utilizing gamma-ray spectrometric techniques. Data generated are being made publicly available on the completion of individual projects.

The hydrogeochemical survey features are listed in Table 4. This will be a systematic national survey of the uranium and associated trace-element content of surface and underground waters being carried out by ERDA laboratories. Data generated will provide a means of identification of favorable areas, particularly when coupled with other available data.

The ERDA programs involve a continuing review of the uranium-resource situation, analysis of the activities and success of industry, and their relation to the desirable resource levels needed in the years ahead to assure adequate uranium supplies to meet the country's needs. The program is geared to providing information to government and industry so that sound decisions can be made on energy policy.

Table 3. ERDA Aerial Radiometric Reconnaissance Program

Goal: Complete airborne radiometric survey of United States (including Alaska) on wide-spaced flight lines by 1 January 1980, to aid in identifying favorable areas.

Program - Minimum total flight line kilometers - conterminous United States, 1,200,000; Alaska, 180,000.

Flight line spacing - 1.5 to 20 km; average 8 km.

Altitude - 60 to 240 m above ground level; optimum 120 m.

Systems - Computerized high-sensitivity gamma-ray spectrometric and magnetic detectors; mounted in fixed-wing and rotary-wing aircraft operated by private firms.

Output - Radiometric equivalent of uranium, thorium, and potassium, and magnetic characteristics of enclosing rock, statistically evaluated by geologic units.

Data handling:

Publication - Open file on completion of each survey.

Summarized data bank - Los Alamos Scientific Laboratory.

Tentative schedule:

Fiscal year	Line kilometers
1974-76	240,000
1977	237,000
1978	583,000
1979	<u>338,000</u>
	1,400,000

Table 4. Hydrogeochemical and Stream-Sediment Reconnaissance Program

Goal: A systematic determination of the distribution of uranium and associated trace elements in surface and underground waters and in stream sediments in the United States (including Alaska) to identify areas favorable for uranium-mineral occurrence.

Participants: National laboratories; universities; State agencies; U. S. Geological Survey; Environmental Protection Agency.

Operating parameters:

Sample spacing - 26 km² (wide area); 1.3 km² (detailed) depending on geologic homogeneity of area.

Analysis - Field concentration of elements from water; measurement of conductivity and pH; determination of specific elements.

Data treatment - Statistical analysis.

Data interpretation - Relate anomaly data to geologic environments.

Output - Areas of favorability; open-filing of maps and data; national data bank.

Tentative schedule:

Fiscal year

1975 - Literature search and limited research and development.

1976 - Pilot studies; statistical methods development; staffing.

1977 - 1979 - Large-scale surface and subsurface sampling; data analysis, interpretation, and reporting.

High-Cost Resources

As previously noted, an alternative to identification of additional low-cost resources is the utilization of higher-cost resources. The highest cutoff-cost category included in ERDA resources for several years has been \$30/lb U_3O_8 . This level was selected a few years ago as an upper range of what might be of interest for utilization in light water reactors over the next decade or more. A preliminary estimate of \$50 resources was made for the first time as of January 1, 1977.

The increased price of oil and coal in the last few years has increased the cost of uranium economically acceptable in light water reactors. This results from the relative insensitivity of nuclear electric-power costs to increases in uranium prices. The cost of fuel is only a fraction of the cost of power from a nuclear plant. In turn, the cost of natural uranium is only a fraction of the fuel cost; enrichment, fabrication, reprocessing, and carrying charges making up the balance. As a result, large increases in uranium prices result in comparatively small increases in power costs. This is an important advantage for nuclear power and provides additional assurance that uranium supplies will be adequate.

Knowledge of U.S. resources in the above-\$30 category is meager, largely because of the lack of past economic interest. There has been virtually no industry activity to search for or develop such resources. Prospects for discovery of higher-cost resources in the U.S., including those types of deposits known elsewhere in the world, such as those listed in Table 2, are considered promising at this stage of U.S. exploration. The magnitude of such resources

is, however, uncertain. The ERDA assessment program will also consider these types of resources.

In addition, there are large very-low-grade deposits that have been studied in some detail in the past. These include shales, granites, and phosphates.

The Chattanooga shale in Tennessee is of particular interest because of its large size. This deposit was extensively drilled, sampled, and studied in the 1950s. The higher grade part of the Chattanooga shale has a uranium content of about 60-80 ppm. It contains in excess of 5,000,000 tons of U_3O_8 that may be producible at a cost of \$100 or more per pound of U_3O_8 . Inasmuch as additional work developing production technology will be needed, it is of interest to note that plans have been announced to exploit a similar but considerably higher-grade deposit (300 ppm) in Sweden. The mining and milling technology has been developed and the deposits are economic.

Similar production technology could be used for the Chattanooga shale at higher prices. As an example, if shale were mined to fuel a 1150-MWe reactor, assuming recycle of uranium (but not of plutonium) and a 0.3% enrichment tail, about 12,600 tons of shale would have to be processed each day--or with uranium and plutonium recycle and 0.20% enrichment tails, about 8500 tons per day. An average of about 11,300 tons of coal would need to be burned each day if 20 MJ/kg (8700-Btu/lb) coal were used.

Utilization of the very-low-grade resources such as Chattanooga shale would, of course, involve mining and processing very-much-larger quantities of ore than is currently mined to produce the same amount of uranium. From an environmental

as well as from an economic point of view, identification and utilization of additional higher-grade ores would be preferable. However, the shales are available if their use should become necessary.

Foreign Uranium

In October 1974, the AEC announced its plan for allowing enrichment of foreign uranium intended for use in domestic reactors.⁵ The plan would allow 10% of an enrichment-customer's feed to be of foreign origin in 1977. The allowable percentage would increase in subsequent years as shown in Table 5. In 1984 there would be no restriction on use of foreign uranium. Therefore, foreign uranium will be an additional source of uranium to meet domestic needs. During 1976, 2900 tons of foreign uranium were delivered to U.S. buyers and 46,000 tons of foreign uranium were under contract at the beginning of 1976 for delivery to U.S. customers through 1990.³

Resources of foreign countries, up to the \$30/lb category, are tabulated in Table 6. The "reasonably assured" category corresponds closely to the domestic-ore-reserve category and the "estimated additional" category corresponds to the domestic-probable potential. As noted in the table, foreign resources are largely contained in five countries: Australia, Canada, South Africa, South-West Africa, and Sweden. All except Sweden, and to some extent Canada, will be essentially uranium-exporting countries because their own needs will be comparatively small. The Swedish uranium is contained in low-grade shale as previously noted and is not likely to be available for export in significant quantities.

Table 5. Allowable Foreign-Uranium-Enrichment Feed--Domestic End Use

Calendar Years	Schedule of Percentage of Feed Allowed to be Foreign
1974	0
1975	0
1976	0
1977	10%
1978	15%
1979	20%
1980	30%
1981	40%
1982	60%
1983	80%
1984	No restriction

Table 6. Foreign Resources (thousand tons U_3O_8)

Country	Reasonably Assured	Estimated Additional
\$15/lb U_3O_8		
Australia	430	104
South and South-West Africa	242	8
Canada	189	394
Niger	52	26
France	48	33
Algeria	36	
Gabon	26	6
Spain	13	11
Argentina	12	20
Other	56 ^a	26
Total (rounded)	1100	630
\$30/lb U_3O_8		
Australia	430	104
Sweden	390	
South and South-West Africa	259	96
Canada	225	787
France	71	52
Niger	65	39
Algeria	36	
Spain	30	55
Argentina	27	50
Other	150 ^b	110
Total (rounded)	1780	1290

^aIncludes Brazil, Central African Republic, Germany, India, Japan, Mexico, Portugal, Turkey, Yugoslavia, and Zaire.

^bIncludes (in addition to ^a) Denmark, Finland, Italy, Korea, and the United Kingdom.

Foreign uranium demand, principally for the countries of Western Europe and Japan, is projected to grow even more rapidly than in the United States. ERDA projections indicate cumulative non-Communist foreign requirements through the year 2000 could be 1.7 million to 2.0 million tons of U_3O_8 with annual demand in 1980 of 28,000 to 33,000 tons and in 1990 of 79,000 to 94,000 tons (at 0.2% to 0.3% tails; with constrained U and Pu recycle).

Existing foreign production capacity is about 20,000 tons/year. Considering the magnitude of known foreign uranium resources and production-expansion plans, foreign capability could be increased to over 50,000 tons/year by 1980 and over 80,000 tons/year by 1985. Although foreign resources are large, there are limitations on attainable production levels from Canadian and South African resources, and continued growth of foreign production capability will require enlargement of the foreign-resource base or use of higher-cost resources.

The prospects for expansion of foreign uranium supplies from a geologic point of view are good. The experience in Australia, where large new resources were identified in just a few years effort, is an example. The absence of substantial known resources in South American and in many African and Asiatic countries as seen in Figure 9 emphasizes the lack of exploration effort that has been done in these areas. However, there are political limitations on the degree to which exploration will be accomplished in such places and the degree to which uranium supplies can be exported. Nationalistic policies toward resources has made access to supplies difficult in recent years. The improvement of world prices and markets should assist in opening up new areas to uranium exploration. However, inasmuch as uranium demand will be low in many countries,

EXCLUDES PEOPLES REPUBLIC OF CHINA, USSR, AND
ASSOCIATED STATES OF EASTERN EUROPE

Fig. 9. World Uranium Resources Reasonably Assured Reserves
@ \$15/lb U_3O_8 . (\$15/lb = \$33/kg)

material should be available in the world marketplace in time to make a useful contribution to U.S. needs.

Fuel-Cycle Practice

There are a number of management and technical decisions relating to nuclear-power utilization that will have significant impact on uranium demand. An important factor relating to operation of light water reactors involves the selection of tails assay at the enrichment plants. For example, enrichment with a 0.2% tails assay (instead of 0.3%) reduces uranium demand by about 20%. Recycle of uranium and plutonium would allow more efficient use of fuel and reduce demands for newly mined uranium. Successful development of a commercial

breeder reactor would, in time, reduce growth in uranium demand. This reactor may not require any natural uranium for centuries, being able to use the several hundred thousand tons of depleted uranium that will be accumulating in the next few decades at enrichment plants.

Conclusion

ERDA assessment of uranium resources indicates that currently estimated \$30 ore reserves byproduct and probable potential resources are 1,900,000 tons U_3O_8 , and total currently estimated \$30 domestic resources are 3.5 million tons. At \$50 the estimates are 2.3 and 4.3 million tons respectively. Further expansion of U.S. uranium supplies is possible by discovery of new low-cost resources, utilization of higher-cost resources, or importation of foreign uranium. ERDA programs are designed to improve understanding of current resources and to aid in identification of new resources, seeking to assure that uranium supplies will be available when needed.

Prices have increased to levels that make exploration and production economically attractive. Industry-exploration and -development activities are increasing. Foreign uranium supplies will be available to augment domestic resources. There is a high probability that additional intermediate-cost resources can also be identified, and there are known domestic high-cost resources that could be used if needed.

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