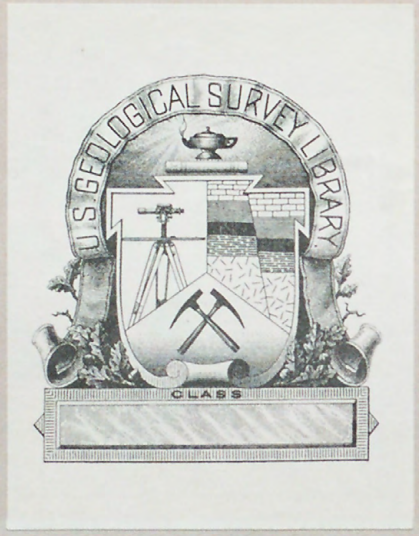
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URANIUM IN PHOSPHATE ROCK

By

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URANIUM IN PHOSPHATE ROCK

By James B. Cathcart

Abstract

Uranium is a trace constituent of all apatites in amounts that typically range from <0.001 to 0.003 percent for guano and guano-derived deposits; from 0.001 to 0.010 percent for igneous apatites; from 0.005 to 0.030 percent for marine phosphorites. Uranium may be enriched to as much as 0.05 percent in phosphorites reworked in a marine environment, and isolated bones and concretions may contain as much as 0.8 percent uranium as a result of enrichment by ground water.

Uranium as U(IV) replaces calcium in the apatite structure. Possibly some U(VI) occurs as UO_4^{-2} groups. Uranium is readily removed from apatite by weathering, and enrichment of phosphate after deposition may be entirely residual, as in the case of the brown rock deposits of Tennessee, or uranium may be added as in the case of the lateritic weathering of the deposits in Florida.

Uranium has been recovered as a byproduct of the manufacture of phosphoric acid by the wet process. In 1972, about 15 million tons of phosphate rock was used to make phosphoric acid in the United States. This phosphoric acid probably contained about 1500 tons of uranium. An additional 10 million tons, worldwide, was made into phosphoric acid, and thus, 1000 tons of uranium was in solution. Increased demand for phosphatic fertilizers and increases in the amount of phosphate rock used to make phosphoric acid makes it likely that tonnages of uranium in phosphoric acid will reach 5000 tons per year within the next 25 years. Thus, marine phosphorites are a significant source of uranium for the future.

Introduction

Uranium is present as a trace constituent in all apatites, in amounts that typically range from 0.003 to 0.030 percent. Strutt (1908) first discovered that phosphatic rocks and fossil bones are appreciably more radioactive than the average rocks of the crust and his data that showed that certain British phosphorites and fossil bones contained from 0.005 to 0.015 percent U_3O_8 were remarkably accurate. Wells (1929) pointed out that a shark's tooth from the Pliocene of Florida contained 0.021 percent U--the first published record of the uranium in the phosphate deposits of Florida, and Hébert (1947) stated that as early as 1924 it was known that the Cretaceous and Eocene phosphorites of Algeria contained uranium. The first mention of uranium in the Cretaceous and Tertiary phosphate deposits of the USSR was published by Rusakov (1933).

The developments of uses of uranium as an energy source provided the impetus for research into all potential sources, and apatites from all parts of the world were tested for uranium. Detailed studies of uranium in phosphate have been made by Altschuler (1973), Altschuler, Clarke, and Young (1958), Altschuler, Jaffe, and Cuttitta (1956), Cathcart (1956), Davidson and Atkin (1953), McKelvey (1956), McKelvey and Carswell (1956), McKelvey, Everhart, and Garrels (1955), and Sheldon (1959). Much of the data presented in this paper is derived from these works, and each of them contains an extensive bibliography.

Phosphorus is found in minable concentrations in three environments--as guano or in deposits derived from guano, as igneous apatite, and as marine phosphate deposits; and in secondary deposits formed from each of these by weathering.

Guano and guano-derived deposits

Guano deposits are formed from the excreta of sea birds and from the excreta of bats in caves. Guano derived deposits are formed when the soluble phosphate in guano is dissolved by ground water and reacts with the underlying rocks to form apatite when the rock is limestone or to form iron and aluminum phosphates when igneous rocks underlie the guano.

About 5 percent of the world's production of phosphate is from guano-derived deposits, and a very small amount is from deposits of guano (table 1). Guano contains from less than 0.001 to about 0.003 percent U (Altschuler, and others, 1958), but guano-derived deposits contain as much as 0.008 percent (Davidson and Atkin, 1953). Recent analytical data (U.S. Geological Survey Denver Laboratory: E. J. Fennelly and Johnnie Gardner, analysts) show that guano-derived phosphate from Curacao contains 0.002 percent U, and that from Nauru contains 0.005 percent. The higher uranium contents (0.005-0.008 percent) are from those samples that are also high in fluorine, that is, in which the phosphate mineral is a carbonate fluorapatite, rather than a hydroxyapatite. The samples are from tidal zones where fluorine and uranium were added from sea water. (A C ✓ Y 1958)

Igneous apatite deposits

Apatite deposits of igneous origin occur as intrusive masses, as veins, as marginal differentiates, or as pegmatites. The largest deposits are intrusive masses associated with alkalic rocks, such as carbonatite, nepheline syenite, pyroxenite, and ijolite.

The apatite mineral is a fluorapatite, and ranges in amount from a few percent as an accessory mineral to as much as 80 percent in some pipes and sheets. The apatitic masses range in size from a few square metres to tens of square kilometres and the amounts of apatite present range from a few tons to hundreds of millions of tons. The largest deposits include those from the Kola Peninsula (USSR), Palabora and eastern Uganda (Africa) and Araxa (Brazil). In 1970, about 17 percent of the world's production of phosphate came from igneous apatite deposits, and about 80 percent of this production was from the deposits of the Kola Peninsula.

The uranium content of primary fluorapatite of igneous rocks typically ranges from 0.001 to 0.010 percent (Altschuler, and others, 1958; Davidson and Atkin, 1953), although individual samples may contain as much as 0.079 percent U (table 2). Thorium is not usually present, except in very minute amounts, but an apatite sample from a pegmatite from Bahia, Brazil contained 0.005 percent U and 1500 ppm Th (thorium analysis by Nancy Conklin, and uranium analysis by E. J. Fennelly, U.S. Geol. Survey).

Table 1.--Guano and guano-derived phosphate: reserves, production and uranium content.

Location	Reserves (metric tons)	Production (metric tons per yr)	Uranium content (percent)
Bird guano			
Peru--Pacific Coast	Limited, renewable small	0.1×10^6	<0.001-0.003
Chile-Pacific Coast		0.01×10^6	
Cave (bat guano)			
Mexico	Very small, total is about 3×10^6	$0.02\text{-}0.04 \times 10^6$	
Philippines			
Africa			
Guano-derived (calcium phosphate minerals)			
Nauru Island	100×10^6	1.8×10^6	0.005-0.007
Christmas Island	30×10^6	0.7×10^6	0.008
Makatea Island	10×10^6	$.3 \times 10^6$	0.006
Ocean Island	10×10^6	$.3 \times 10^6$	0.001-0.002
Curacao	30×10^6	$.1 \times 10^6$	0.002
Anguar	2×10^6	----------	0.001
Guano-derived (iron and aluminum phosphate minerals)[1]			
Malpelo Island, Colombia	0.4×10^6	None	No data
Trauira Island, Brazil	11×10^6	None	No data
Saldanha Bay, South Africa	0.3×10^6	None	No data
Kito-Daito-Jima Ryukyu Islands	2×10^6	None	No data

[1]Only the largest of the aluminum and iron phosphate deposits are listed. Others are known, but reserves are limited and none are being mined today. The deposits of Kito-Daito-Jima have been mined. Uranium contents of these deposits are not known, but are thought to be small, of the order of magnitude of 0.001 percent.

Table 2.--Igneous apatite: reserves, production and uranium content.

Location	Reserves[1] (metric tons)	Production[2] (metric tons per year)	Uranium content[3] (in percent)
Kola Peninsula--USSR	2×10^9	9×10^6	0.001-0.003
Palabora-South Africa	0.4×10^9	0.6×10^6	0.003-0.004
North Korea	0.1×10^9	0.2×10^6	No data.
Brazil (carbonatites)	0.15×10^9	0.2×10^6	[4]0.020
Dorowa-Southern Rhodesia	0.1×10^9	0.1×10^6	No data.
Uganda	0.2×10^9	0.01×10^6	[5]0.013-0.030
Antofagasta-Chile	0.02×10^9	0.01×10^6	No data.
Mineville district New York, USA	Very small	None	0.079

[1]In metric tons of total rock containing more than 10 percent P_2O_5.

[2]In metric tons of apatite concentrate containing at least 25 percent P_2O_5.

[3]In percent, of the apatite concentrate.

[4]One sample, from Araxa. A sample of apatite from a pegmatite in Bahia, Brazil, contained 0.010 percent eU, 0.005 percent U, and 1500 ppm Th.

[5]Percent U_3O_8, from Davidson and Atkin, 1953.

Marine phosphorite

Marine phosphorite deposits are known throughout the world and in all geologic ages from Precambrian to Holocene. The richest of these deposits form in basins away from abundant sources of clastic material in warm latitudes in areas of upwelling water. The deposits may be very large--reserves in individual deposits are billions of tons; total reserves aggregate scores of billions of tons, and resources are proportionately larger (Cathcart and Gulbrandsen, 1973). About 84 percent of the world production of phosphate comes from marine phosphorites; from 1970 through 1972 production in the United States has been about 40 million tons per year; 83 percent from Miocene and Pliocene deposits in Florida and North Carolina, 11 percent from the Permian deposits of the western states, and 6 percent from Ordovician deposits in Tennessee and Alabama. Some production from the Miocene of California is included in the total for the western states.

Every deposit that has been analyzed contains uranium, in amounts that typically range from 0.005 to 0.030 percent, while the average uranium content for most deposits is in the range from 0.005 to 0.010 percent (table 3). The relative uniformity of the analytical data indicate strongly that deposits for which data are not available almost certainly contain similar amounts of uranium--that is, ranging from about 0.005 to 0.020 percent and averaging about 0.006-0.008 percent uranium.

Uranium is associated with the apatite mineral (carbonate fluorapatite), and most workers agree that uranium as U(IV) replaces calcium in the apatite structure (Altschuler and others, 1958).

The uranium-apatite association is clearly demonstrated by several lines of evidence, for example, chemical analyses of the minerals associated with apatite in the Florida deposits show that they contain virtually no uranium; in a general way, uranium varies directly with P_2O_5 content (Cathcart, 1956, Thompson, 1953 and 1954); and the amount of uranium dissolved on acidulation of phosphate rock varies directly with the amount of phosphate dissolved (Igelsrud and others, 1948).

Table 3.--Marine phosphorite: reserves, production, and uranium content.

Location	Reserves[1]	Production[1]	Uranium content[2]
United States			
Central Florida	2.1×10^9	35×10^6	0.003-0.030, average concentrate = 0.011, average pebble = 0.015.
North Florida-South Georgia	0.3×10^9		0.004-0.011, average = 0.006.
North Carolina	2×10^9		0.004-0.011, average = 0.006.
North Georgia (Savannah River)	Reserves not measured; resources are billions of tons	No production	0.005
South Carolina (Beaufort County)			0.006
(Charleston area)			0.005-0.037
Florida-Georgia (Hawthorn Formation)			0.003-0.008, average = 0.005.
Idaho, Montana, Utah, Wyoming (Phosphoria)	6×10^9	4×10^6	0.002-0.021, average = 0.009
Utah (Brazer lst)	Measured reserves are small; resources, particularly in Alaska are billions of tons	No production	0.001-0.006
Alaska (Permian)			0.001-0.024, average = 0.008.
Others (Ala. Ark., Ky., Iowa, Kans., Okla., Calif., Nevada)			Rock: 0.001-0.014; nodules: 0.009-0.030 in black shale and limestone.
Africa			
Algeria	20×10^9	0.1×10^6	0.011-0.014
Angola		---	No data.
Morocco		10×10^6	0.007-0.023
Senegal		0.7×10^6	0.012-0.018
Togo		1×10^6	No data.
Tunisia		3×10^6	0.004-0.009
U.A.R. (Egypt)		0.6×10^6	0.007-0.012
Spanish Sahara		---	0.005-0.011

Table 3.--Marine phosphorite--Continued:

Location	Reserves[1]	Production[1]	Uranium content[2]
		Asia	
China	1×10^9	1×10^6	No data.
Laokay-North Vietnam	0.1×10^9	1×10^6	No data.
India	0.1×10^9	0.1×10^6	0.003-0.100
Iran	0.05×10^9	---	No data.
Iraq	0.1×10^9	---	No data.
Israel	0.1×10^9	1×10^6	0.002-0.020
Jordan	0.1×10^9	0.5×10^6	No data.
Mongolia	1×10^9	No data.	No data.
Saudi Arabia	0.2×10^9	None	0.002-0.011 average =0.006.
Turkey	0.2×10^9	None	0.004
Australia	1×10^9	None	0.001-0.013 average =0.009
		Europe	
USSR	1×10^9	5×10^6	0. 05-0.010
Others (Belgium, Germany, France England, Spain)	Small	0.1×10^6	0.001-0.021 average =0.006
		Latin America	
Mexico	0.15×10^9	Production is a few tens of thousands of tons per yr.	No data.
Colombia	0.2×10^9		0.004-0.012 average =0.008.
Venezuela	0.1×10^9		0.005
Peru (Sechura)	$1+ \times 10^9$		0.006
Brazil (Bambui)	Small		0.001-0.005 average =0.002

[1]In metric tons of recoverable phosphate product containing at least 24 percent P_2O_5.

[2]Uranium in percent, of the phosphate product, except as noted.

The syngenetic character of uranium in marine phosphate is well demonstrated in the distribution in the Florida phosphate deposits. Primary phosphate pellets in the Hawthorn Formation are low in uranium content--average about 0.005 percent. The phosphate pellets in the overlying Bone Valley Formation were reworked from the Hawthorn Formation in a marine environment, and the concentrate size particles (the pellets) contain an average of 0.011 percent U (table 3). The pebble fraction (+1 mm) contains an average of 0.015 percent U, and the coarse pebbles that show evidence of several cycles of reworking in the marine environment contain as much as 0.05 percent U (Cathcart, 1956, Altschuler and others, 1958). Thus, primary pellets contain the least amount of uranium, pellets reworked once in a marine environment contain much more uranium, and pebbles reworked several times contain the most uranium. That uranium was not emplaced by ground waters percolating through the deposits is indicated by the fact that the fine-grained pellets, highest in P_2O_5 content, always contain less uranium than the lower-P_2O_5-content pebble fraction even in deposits that contain 90 percent fine phosphate pellets and only 10 percent pebble size.

Uranium in solution in ground water is taken up by apatite, and phosphatic bones, concretions, pellets and pebbles may be strongly enriched in uranium. Thus, isolated bones may contain up to 0.83 percent uranium (Altschuler and others, 1958), individual concretions and nodules as much as 0.1 percent (Davidson and Atkin, 1953), and individual samples of pellets from Florida as much as 0.5 percent. These abnormally high contents of uranium are cited to indicate the amount of enrichment that can be accomplished under special conditions.

Under normal marine conditions, the extremely small amount of uranium in sea water probably accounts for the low, rather uniform content of uranium in these apatites.

Secondary deposits

Uranium is readily leached from apatite during weathering and under acid ground water conditions both apatite and uranium are dissolved. The end products of weathering and the distribution of uranium in the products depend on the type of source rock and the length and severity of the weathering.

When the original rock is a phosphatic limestone, weathering removes calcite, leaving a residually enriched phosphorite. In the case of the residual "brown rock" deposits of Tennessee, both the uranium and the P_2O_5 contents are increased in the residual material by the same factor--there is no preferential enrichment of uranium. When calcite is gone, the apatite goes into solution and moves downward where it replaces the underlying limestone. In replacement deposits there tends to be a preferential enrichment in uranium, and uranium contents of as much as 0.1 percent have been noted in the secondary apatite hardpan on the Cooper Marl of South Carolina (Altschuler and others, 1958).

Replacement type deposits are known in many parts of the world. Individual deposits tend to be small, irregular in shape, and high in P_2O_5 content. Uranium contents typically range from 0.001 to 0.017 percent (table 4), although much higher contents are known. Measured reserves are small, but total resources may be fairly large.

Intensive weathering by acid ground water of sandy phosphorites produces irregular zones of porous, vesicular, light-colored, and lightweight rocks characterized by aluminum phosphate minerals. These zones have been described from Florida, Nigeria, Senegal, and Siberia (Altschuler, 1973). All of the deposits are similar and are characterized by the change of apatite to crandallite or millisite and to wavellite as an end product. These changes are accompanied by the change of the original clay minerals (montmorillonite or illite) to kaolinite.

Uranium is enriched in these deposits, and it is associated almost entirely with the phosphate minerals, and preferentially with the calcium aluminum phosphate minerals--crandallite and millisite, or with the calcium phosphate mineral apatite. The uranium minerals autunite (from

Table 4. Secondary phosphate deposits: reserves, production, uranium content

Location	Reserves	Production	Uranium content
Replacement deposits--calcium phosphate			
Florida-hardrock	0.05×10^9	none	0.001-0.017; -200 mesh from 0.001-0.023.
Tennessee-"whiterock"	small	none	0.004
South Carolina "phosphatic hardpan"	v. small	none	0.035-0.12
Venezuela Riecito area	0.01×10^9	"few thousand tons per year"	no data
Russia	no data	no data	0.001-0.010[1]
Residual deposits--calcium phosphate			
Tennessee "brown rock"	0.08×10^9	3×10^6	0.001-0.003[2]
Aluminum phosphate deposits			
Florida land-pebble district	0.05×10^9	none	0.004-0.040[3]
Senegal	0.05×10^9	0.1×10^6	no data
Nigeria	v. small	none	0.004-0.011
Siberia-USSR	no data, small(?)	none	no data

[1] Uranium analyses by E. J. Fennelly and Johnnie Gardner, U.S. Geol. Survey, Denver.

[2] Unaltered limestone from which the residual deposits formed contains 0.0004 percent U.

[3] Typical range in uranium contents. Individual samples may contain as much as 0.3 percent U.

Florida) and torbernite (from Morocco) have been reported from the aluminum phosphate zones, but only in trace amounts and only in limited areas within the deposits. Uranium is highest and most enriched in the porous, partly leached apatite pebbles at the base of the zone of leaching, and amounts of uranium are as high as 0.3 percent in these pebbles. Concentrates of the calcium aluminum phosphate minerals crandallite and millisite contain as much as 0.05 percent uranium (Altschuler, 1973), but concentrates of the aluminum phosphate mineral wavellite contain almost no uranium, probably averaging only about 0.003 percent.

In Florida, the total zone of aluminum phosphate alteration may be enriched in uranium, as much as 2 to 4 times over the original, unaltered calcium phosphate zone from which it was derived.

Uranium is liberated during the solution of the apatite, remains soluble in the descending acid solutions and enriches the crandallite and the partly leached apatite pebbles at the base of the section. Because wavellite is continuously formed from crandallite in the middle parts of the zone, the uranium in the crandallite goes into solution and moves downward to further enrich the underlying apatite, accounting for the abnormally high uranium contents in some of this apatite.

Other deposits

Lake beds

Tertiary lake beds in Wyoming and Nevada contain some beds of uraniferous phosphate. Lake beds near Tonopah, Nevada, contain 6.7 and 11.0 percent P_2O_5 and 0.10 and 0.12 percent eU (unpublished analyses, U.S. Geological Survey, by Carmen Johnson and Maryse Delevaux). Lake beds of Eocene age in Wyoming and Utah contain as much as 0.27 percent U and 19 percent P_2O_5, although average contents of both are much less (Love, 1964). Many very thin beds containing the phosphate and uranium are present; the beds average less than a foot in thickness. The uraniferous phosphate beds are thought to be syngenetic, and although these occurrences are not economic, they indicate the possiblity that in other, similar lake

basins, economic beds of uraniferous phosphate might be present. Tonnages are not known; they may be large in aggregate because of the extent of the beds, but tons per unit area are probably small.

Offshore deposits

Phosphate nodules and pellets are present on the floors of the modern oceans and have been investigated on the west coast of North America from Monterey Bay south to Baja, California, on the east coast of the United States from North Carolina to Florida, and along the west coast of Africa.

Some of the nodules are thought to be forming in the modern oceans (as those of offshore California); others are thought to be reworked from older phosphatic sediments (those of offshore North Carolina and the west coast of Africa).

Amounts of pellets and nodules in the modern sediments range from traces to as much as 60 percent by volume, but probably average between 5 and 10 percent, and resources probably aggregate billions of tons although adequate measurements of reserves have not been published.

Uranium contents range from 0.001 to 0.012 percent (Altschuler and others, 1958), and a single sample from offshore California contained 26.4 percent P_2O_5 and 0.021 percent U (U.S. Geological Survey analysis by M. Finch, C. Angelo, and P. Schuch). The analytical data are similar to data from older marine phosphorites, and there is no reason to believe that other deposits, not analyzed, will contain very different amounts of either uranium or phosphate.

Phosphate and uranium resources

Phosphate reserves, defined as identified mineral deposits whose grade and tonnage are reasonably evaluated and may be economically recoverable under present conditions, along with their uranium contents are given in tables 1 through 5. All reserves are in metric tons of mineral that contains at least 24 percent P_2O_5. The uniformity of uranium content of marine phosphorites (0.006-0.010 percent) is striking and indicates that average U content and total resources are probably reasonable numbers. Data on phosphate resources of the world are given by Cathcart and Gulbrandsen (1973) and these data are summarized and brought up to date (July 1974) in table 6. Average uranium content and total uranium resources are also indicated in the table.

Uranium has been recovered as a byproduct only in the manufacture of phosphoric acid by the wet process. Newspaper articles (early 1974) indicate that plans are being made to again recover uranium from phosphoric acid by the same process, but which has been technically improved. Available data clearly indicate that uranium is recoverable only from phosphoric acid. Thus, of the total amount of uranium present in the phosphate resources (table 6), from one-third to one-half, is potentially recoverable because these fractions are being and will be made into phosphoric acid. The latest available data show that about 15 million tons, about one-third of the total production of phosphate rock in the United States, went into the manufacture of wet process phosphoric acid (Stowasser, 1972). The phosphate rock used in phosphoric acid production probably contained an average of 0.010 percent U, and, therefore, contained 1500 tons of uranium.

Projections for the future are speculative, but the needs of an increasing population for fertilizer indicate that the production of phosphate will increase in the future. Latest figures for planned increases in capacity indicate that by 1980 the United States will have the capacity to produce almost 60 million tons per year of rock phosphate, an increase of about 50 percent from the production of about 40 million tons of rock in 1973. World capacity by 1980 should be 160 million tons

Table 5.--Other phosphate deposits: reserves, production, uranium content.

Location	Reserves	Production	Uranium content
	Lake beds		
Nevada (Tertiary)	Probably small	None	0.10, 0.12
Wyoming, Utah (Eocene)	Area is large, but beds range from 3" to 6' in thickness	None	0.001-0.29 average = 0.005.
	Offshore		
California (Monterey Bay to Baja, Calif.)	Large	None	0.001-0.021
Florida, Georgia, South and North Carolina	Large	None	No data, probably average 0.005.
South Africa Capetown	No data, maximum apatite content is 15 percent	None	No data.
Northwest Africa Rabat to Mauritania	No data, apatite content 10-60 percent, reworked from older beds	None	No data, but U content should be the same as the deposits of North Africa, from which these deposits probably were derived.

Table 6.--Resources of uranium in sedimentary phosphorites.

[Modified from table 106 Cathcart and Gulbrandsen (1973).

In metric tons of rock containing 20 percent or more P_2O_5.]

	Identified resources[1/]	Hypothetical resources[2/]	Percent uranium[3/]	Total tons uranium[4/]
United States----------	10×10^9	25×10^9	0.009	3,150,000
Africa----------	45×10^9	50×10^9	.009	8,500,000
Near East and Asia----------	10×10^9	10×10^9	.008	1,600,000
Latin America----------	5×10^9	5×10^9	.008	800,000
Australia----------	3×10^9	10×10^9	.006	780,000
Pacific Islands----------	0.2×10^9	0.1×10^9	.005	15,000

1/ Identified resources are defined as identified mineral deposits that may or may not be evaluated as to extent and grade, and whose contained minerals may or may not be profitably recovered with existing technology.

2/ Hypothetical resources are defined as undiscovered mineral deposits, whether or recoverable or subeconomic grade, that are geologically predictable as existing in known districts.

3/ Percent uranium is a reasonable average taken from tables 1, 2, and 3 in this report.

4/ Total tons of uranium is metric tons present in the identified plus hypothetical resources.

as compared with 110 million in 1972. At a production of 60 million tons per year, reserves in Florida and North Carolina will last until about 2000, after which the production rate from this area will decrease, and the slack will have to be taken up by the western deposits. If these numbers are correct, by 1980, the United States will be using 20 million tons of phosphate rock per year for making phosphoric acid. If demand for phosphate rock continues to increase, the United States in the year 2000 will use about 50-60 million tons of phosphate rock per year for making phosphoric acid (F. E. McGinley, USAEC, written commun., 1974). The amount of uranium in phosphoric acid in the United States, then, will increase from 1500 tons per year in 1972 to 2000 tons per year by 1980, and potentially to as much as 6000 tons per year by 2000. If the rate of increase is uniform, by the year 1980 13,400 tons of uranium could be produced from phosphoric acid, and by the year 2000, more than 95,000 tons could be produced. These figures assume that production of uranium will be from all of the phosphoric acid made. Certainly, production will not be this high, and McGinley (written commun., 1974) estimated that production recovery from acid would be about 90 percent, and that about 70 percent, of the total acid produced would be treated in uranium recovery plants by 2000. The totals would then be reduced to about 60,000 tons of uranium that might be recovered in the years 1975-2000.

The very large amounts of phosphate projected for use by the year 2000 are in excess of what can be produced in the eastern United States, unless there is added production from the north Florida-south Georgia area, the Savannah River area of north Georgia, the North Carolina field, and possibly the southern extension of the Bone Valley district of central Florida. It seems probable that imports of phosphate rock and production from the western United States will have to increase drastically before the end of this century to take care of potential demands for phosphate rock. A substantial portion of the total production of phosphate rock is exported (about one-third in 1973), but planned increases in capacity throughout the world indicate that our exports will decrease in the future.

The total tonnage of uranium present in the phosphorites of the United States, particularly the large hypothetical resource, might lead to misapprehension as to the total amount of uranium that can be recovered from this source. First, much of the hypothetical resource is probably not minable, for a variety of reasons. Second, uranium can be recovered only from phosphoric acid made by the wet process--i.e., by treating phosphate rock with sulfuric acid. Projections for the near future--capacity increases to 60 million tons of rock that could be mined, and 20 million tons used to make phosphoric acid by 1980, are realistic--they are based largely on announced increases, and there is little chance that these numbers can be substantially increased because, for example, of difficulties in obtaining special steels needed for chemical plants, draglines, and so on. The longer range projections are based on what seem to be realistic guesses on amounts of phosphate rock that will be needed to satisfy the demands for phosphate fertilizer.

If all phosphate rock mined were to be converted to phosphoric acid, the total amount of uranium that could be recovered would, of course, be doubled or tripled, but this is not believed possible--first, because of vastly increased amounts of sulfur required, and second, because it would entail the use of vast amounts of phosphate rock for purposes other than fertilizer, and phosphate as a fertilizer is necessary for food production. It might be argued that the phosphoric acid could be stored until needed as a fertilizer material (a difficult proposition, because of its corrosive nature), but it must be mixed with ground phosphate rock (in about equal amounts) to make one of the most used fertilizers--treble superphosphate, or mixed with aqueous ammonia to make diammonium phosphate.

The manufacture of ammonia requires abundant natural gas as a source of hydrogen, and vastly increased amounts of ammonia would be needed if this use is contemplated. Other needs for natural gas, and its overall shortage, would seem to preclude this use for the material.

In short, it is most probable that the projected tonnages for recoverable uranium from phosphate rock are about maximum possible, considering all factors.

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1 ITEMS