UNITED STATES DEPARTMENT OF THE INTERIOR

GEOLOGICAL SURVEY

U.S. Geological Survey Uranium and Thorium Resource Assessment and Exploration Research Program

by

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PREFACE

The U.S. Geological Survey conducts a variety of programs to determine the amounts and availability of energy-related geologic resources and to aid in the management of their development. Four of these programs are devoted to gaining a better understanding of the nature and distribution of (1) oil and gas, (2) coal, (3) nuclear fuels, and (4) chemical resources, with special emphasis on developing an effective resource-assessment capability. Operating under the purview of the Office of Energy Resources, each of these programs involves geological, geochemical, and geophysical investigations of many types. This report describes the background, goals, and directions of the nuclear fuels program, and its significant accomplishments during the past 3 years.

INTRODUCTION

<u>Problems of energy-fuels supply</u>

In 1979, oil and natural gas provided about 75 percent of the energy consumed in the United States. Much of this fuel was imported as the nation became increasingly dependent on foreign suppliers. Nuclear fuel, used almost exclusively for electrical-power generation, provided only about 4 percent of the energy consumed in 1977. Most of the remaining energy needs of the country were met by burning coal.

Production of oil in the United States has been declining since 1970, production of natural gas has been declining since 1974, and increased exploration has failed to improve the picture of economic reserves materially. These facts became a focus of national attention in 1973 when a short-term embargo drastically cut the supply of imported oil and gas. In response, the Government announced policies to increase the use of nuclear fuel and coal. Following this course, however, has proven easier said than done. Coal production has increased, but only slowly because of problems of environmental concern, lack of mining equipment and skilled labor, a major labor strike, transport shortages, as well as regulatory problems and the time lags imposed by the necessity for conversion of electricity-generating plants and other industrial facilities from natural gas to coal.

Increase of nuclear-fuel use has met similar barriers. There is great environmental concern over the safety of nuclear powerplants, and some communities have opted to exclude such plants from their areas. Delays are caused by regulatory procedures and environmental litigation; as a result, the time involved in building a nuclear plant is now typically about 10 years. This lead time, combined with inflating costs of capital equipment and construction, has led utilities to cancel orders for nuclear reactors and postpone or abandon their plans for increasing nuclear power generation; and still more recently new concerns have been raised about safe storage of radioactive wastes produced by nuclear plants.

Still other factors weigh heavily in deciding the future of nuclear power and the need for nuclear mineral fuels. For example, the need for new fuel resources depends upon Government decisions as to whether spent fuel may be recycled, and whether the United States intends to develop breeder-reactor technology in which more fuel is produced than consumed. These two factors involve important problems of establishing absolute security of radioactive materials, as well as geopolitical aspects of encouraging the adoption of nuclear technology which does not produce weapons-grade materials as byproducts. An adjunct to these concerns is that decisions may be made in the future to build reactors which partly or entirely use thorium as fuel instead of uranium--another uncertainty in determining future uranium (and thorium) needs. Other unknowns in the uranium supply-demand equation are whether the United States will have access to foreign supply of uranium in case of need, or whether, if the United States proves to have uranium resources in excess of projected needs, export to other user nations will be considered.

Though the uncertainties are great, nuclear power represents a significant potential element in the United States and world mix; that potential must be understood in policy formulation. As a basis for establishing a national course toward appropriate mixtures of energy sources to serve the Nation's short-, intermediate-, and long-term needs, it is essential to have the best possible assessment of our national uranium and thorium resources. And to achieve that assessment, to clear understanding of the geology of uranium occurrence is essential.

The national need for improved resource assessment

The current state of understanding of uranium-resource availability is illustrated by the conclusions of two reports by expert consultants, prepared in 1977. One report, commissioned by the Ford Foundation, concluded that there will be enough domestic uranium at costs of $40/lb (1976 dollars) for needs to the year 2000, and enough at higher prices to suffice well into the next century. The U.S. Department of Energy and many industry experts have pointed out that current exploration discovery rates, and delay factors in mining discovered ore, indicate that this report is seriously over-optimistic. The other report, by a panel commissioned by the U.S. National Academy of Sciences, is considered by many experts to be too pessimistic. It concludes that a fivefold increase in discovery rates and development of reserves is needed, and that shortfalls in uranium supply will be felt well before the turn of the century--early enough to affect current nuclear plants which have projected 40-year lifetimes. Neither report agrees with current resource estimates by the Department of Energy, which has the assigned responsibility for national uranium resource estimates.

There is ample room for disagreement because the two reports have to embody assumptions about projected demand, discovery rates, mill capacity, and price fluctuations on the national and world markets during the next few decades. And the Department of Energy resource numbers involve calculated extensions of company reserves data into surrounding unexplored ground and assumptions as to probable economic factors in actually producing ore ("forward cost").

What is lacking is a reliable estimate of the basic figure--how much uranium in potentially mineable ore-grade concentrations is in the ground? Such a figure is not easily acquired; after all, no one can truly know what lies waiting to be discovered in undrilled ground. And the art of resource estimation generally involves exercises of subjective probability. One such recent exercise for a major uranium area was done by a group of experts; the individual expert estimates varied by a factor of 1000. Two basic facets are involved in this kind of estimation--(1) geologic information on an area and understanding of uranium habitat in the geologic setting of that area, and (2) the method of estimation of potential resources in unexplored ground. Both facets can be improved.

Good appraisal of regional resources requires new data to be gathered and new estimation methods to be developed or existing ones improved. This must be a continuing effort, with reliability of resource values improving as the basic data and methods improve. Of prime importance is improvement of knowledge about economic uranium mineralization in key producing areas of differing geology. A few such areas contain not only most of the known reserves but also almost certainly a very large percentage of the Nation's undiscovered resources. Better knowledge of the geology and of the modes of uranium occurrence in these key areas will permit a more accurate assessment of unknown ground by comparing it with the geology of the analogous key areas. This knowledge is essential in any attempt to estimate favorability and potential resources outward from deposits into surrounding areas and downward below the typically shallow depths so far drilled. This will also help industry sharpen its efforts to find resources and convert them to reserves and thereby continue to upgrade resource data for known uranium areas. The need for information even in well known sandstone areas is shown by figure 1, in which the decrease in effectiveness of drilling to find ore is evident. This trend can be reversed only by improved understanding of why and how (and therefore where, with luck) uranium deposits are formed.

For uranium in nonsandstone settings, still more basic geologic information is needed because little is known of such occurrences in the United States. Yet the United States has areas that are geologically similar to those elsewhere in the world that contain enormous uranium resources in igneous and metamorphic rocks. We must learn about both the foreign deposits as models and the possibly analogous settings in this country to make reliable uranium resource.

For thorium, the picture is similar. Only one high-temperature gas reactor, which uses thorium as a partial replacement for uranium fuel, has been built, and its operating characteristics are still being assessed. Other reactors which would use more thorium are in the design stage. Another factor affecting future demand is the possibility that other nations planning for nuclear power may adopt technologies which will not produce plutonium byproducts. Thorium reactors could serve this purpose and thus may become more widely used at home and abroad in the future. Accordingly, assessment of thorium resources has become more important, and the estimates may help determine policy and technology direction.

U.S. Geological Survey program and objectives

The U.S. Geological Survey program is designed to improve understanding of the nature and distribution of uranium and thorium resources of the United States. The basic approach is to apply combined geological, geochemical, and geophysical methods of study in known uranium areas in order to discover what aspects control the locations of deposits, the genetic processes by which deposits form, and the geologic history that may have affected first the formation and then the preservation of ore deposits. From this approach come new geoscience insights as well as new geochemical and geophysical techniques and tools which aid the exploration industry in its vital role of finding resources. Other studies focus on frontier areas to extend the information into unexplored terrain. The knowledge gained and the conceptual models built are also meshed with efforts to improve or develop methods of resource assessment. Geological, geochemical, and geophysical data sets are being added to a national computer data base which will be used for integrated analysis of regional characteristics and patterns of uranium and thorium occurrences.

For organizational purposes, the Survey program currently identifies four principal thrusts: (1) areal studies, (2) topical research, (3) data system development, and (4) resource assessment. The areal studies are focused on principal areas of uranium potential; on uranium-resource evaluation of specific 1:250,000-scale quadrangles for the Department of Energy's origran

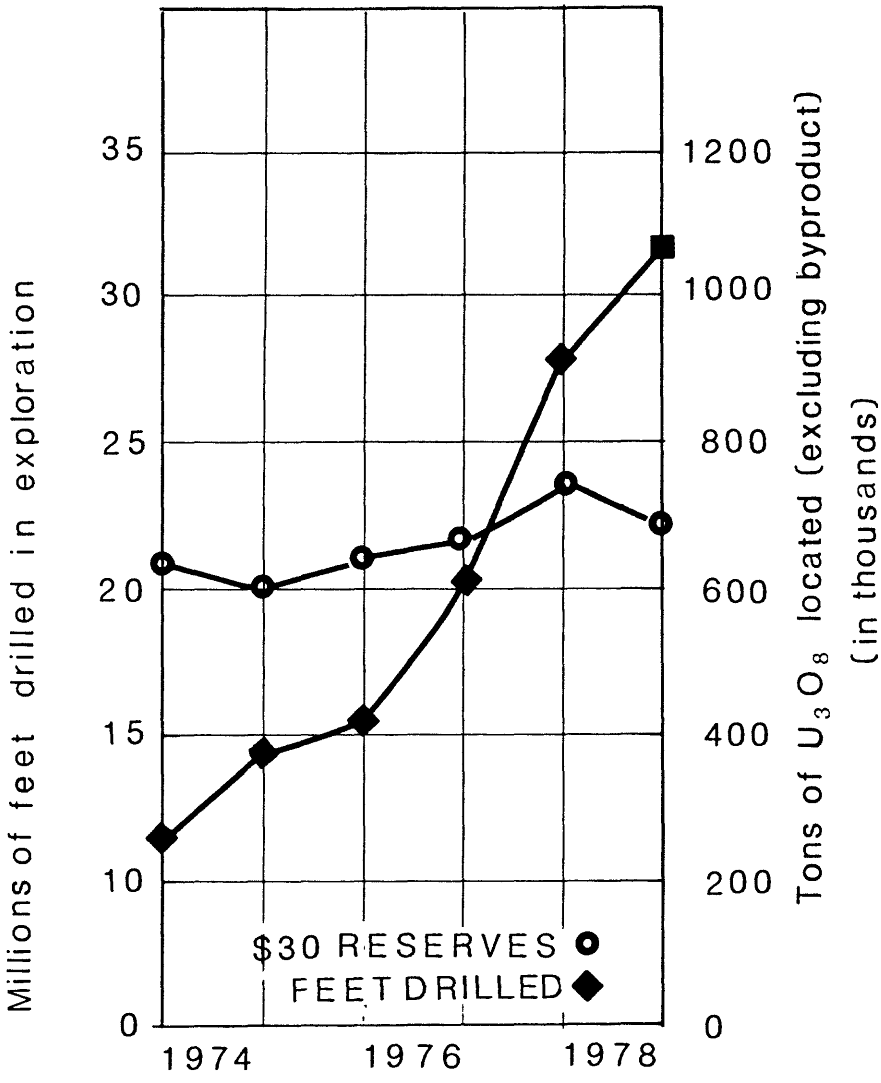


Figure 1.--Graph showing U.S. Department of Energy data on reserves (at \$30/lb U_3O_8 "forward cost") located by exploration drilling, compared with total footage of exploration drilling from the beginning of 1974 to the end of 1978.

described below; and on frontier areas of particular geologic promise. The intent is to map or otherwise demonstrate the occurrence and distribution of rock properties favorable to the origin and entrapment of uranium and thorium. During the past year, two occurrences of uranium which represent types of deposits of major world significance were discovered. Such types of deposits have not yet been developed commercially in this country.

The topical research program is intended to develop models of uranium-thorium occurrence and techniques for identifying and measuring significant parameters which can lead to the discovery and assessment of uranium and thorium. In this regard, geochemical research is carried out to understand and recognize possible source rocks, modes of transportation, and the geochemical characteristics of entrapment sites. To aid this research, instruments are being developed, including a helium-detection device and a bore-hole logging tool, to detect very low levels of occurrence of uranium and its daughter products. In addition, the program includes studies of the depositional environments of uranium, which leads to an improved capability of predicting the distribution of host rocks, as well as investigations of correlation techniques, such as magnetostratigraphy, to permit a more accurate comparison of rock units in the field. Geophysical research is also part of the topical program; it includes most radiometric and nonradiometric techniques, as well as the use of satellite and aircraft remote sensing data to recognize areas potentially favorable for the occurrence of uranium and thorium. The data derived from these various topical and areal investigations must be organized for exploration use by both Government and the private sector. To this end, a computerized data system on uranium-thorium resource occurrence has been developed in the Geological Survey's CRIB format and is in operation.

The resource-assessment component of the program involves research on assessment methodology, such as ways to integrate the geological, geophysical, and geochemical data into a quantitative estimate of resource potential. A major pilot study of a new method of resource estimation currently is being conducted in the San Juan Basin of New Mexico, the site of the Nation's principal resources of uranium. The actual assessment of the national uranium-resource potential is coordinated with the Department of Energy but assessments of local areas, particularly for land-use decisions on wilderness areas, roadless areas, Alaskan D-2 lands, or Indian lands, is carried out by the Geological Survey.

The Geological Survey's uranium-thorium program has been coordinated with the Department of Energy's National Uranium Resource Evaluation (NURE) program since Fiscal Year 1978. The NURE program is a multi-year, three-hundred-million-dollar attempt to estimate the uranium resources of the Nation, to delineate areas believed favorable for the occurrence of additional deposits, and to transfer technology and resource information to industry. Although the Department of Energy has the mandated responsibility for the NURE program, the Geological Survey's research capability has been enlisted, under a memorandum of understanding, and funded to support the NURE effort. The Geological Survey is contributing by mapping and assessing the favorability for uranium in 23 highly prospective 1:250,000-scale quadrangle areas which probably encompass as much as two-thirds of the Nation's uranium resources; the Survey's contribution also includes geological, geochemical, and geophysical research on many phases of ore-forming processes, devising improved methods of resource assessment, and determining the thorium resources of the Nation. With completion in FY 1980 of the main phase of DOE's NURE program and publication of the Geological Survey's thorium estimates, the Branch of Uranium and Thorium Resources will de-emphasize the NURE-type map-quadrangle studies and re-emphasize topical research and other efforts that improve its capability to understand, discover, and appraise uranium deposits. Particular emphasis will be placed on the so-called nonsandstone-environment "world-class" deposits which are important elsewhere in the world but which have not yet received adequate attention in the United States.

Federal authorization for program

The basic mandate for the uranium and thorium program is the Organic Act that established the U.S. Geological Survey in 1879. This Act (43 U.S.C. 31 (a)) authorized the Geological Survey to examine "the geological structure, mineral resources, and products of the Nation domain." More recent authorizations permit the Geological Survey to "conduct geological and geophysical exploration in areas outside the national domain where determined by the Secretary (of the Interior) to be in the national interest" (43 U.S.C. 31 (b)).

ORGANIZATION OF THE URANIUM AND THORIUM RESOURCES PROGRAM

History and staffing of the program

Prior to 1939, uranium was treated chiefly as a chemical curiosity and had limited use as a pigment for porcelain and glass and as an associate of other useful elements, including radium after its discovery by the Curies in 1902. In its role as a curiosity, however, in 1898 it attracted the attention of one of the Geological Survey's first and ultimately among its most reknowned mineral chemists, W. F. Hillebrand. His interests in turn provided incentives in 1903 and 1905 for F. L. Ransome and J. M. Boutwell to undertake detailed investigations of the newly discovered vanadium-rich carnotite ore deposits of the Colorado Plateau. Results of these and later minor studies provided a firm foundation for launching in 1938 an intensive search to find raw materials for development of the atom bomb. The present era of nuclear raw-materials investigations began in 1939, with the beginning of the Colorado Plateau vanadium-uranium project. Intensive studies were made of the geologic habits of the deposits, especially those habits relating to resource appraisal and exploration guides. On the basis of these studies, undiscovered resources were judged to be large enough to meet anticipated military needs even though the then-identified reserves were small. These studies were also the basis for extensive geologic uranium studies and explorations on the Colorado Plateau, and studies elsewhere of other uranium and thorium deposits from 1947 to 1958, in cooperation with the U.S. Atomic Energy Commission. During the 1947-58 period, the Geological Survey budget for these studies averaged about $5 million per year (including $1.5 million for drilling), and in the peak years as many as 160 Geological Survey scientists were assigned full or part time to uranium studies. As a result of these national efforts, the Geological Survey developed geologic guides to ore and exploration techniques that contributed to the finding of the large resources of uranium predicted earlier.

By the mid 1950's, domestic reserves were greater than the military needs, and the nuclear-power industry had not yet emerged, so the Atomic Energy Commission budget for geologic studies and Geological Survey cooperative work was cut back substantially. In 1958 the Geological Survey assumed the geologic studies program with funding of $1.7 million per year. The program was reduced to $1 million and a staff of 12 scientists in 1959 and continued at that level through 1973. In those years the program consisted of finishing key studies underway when the Atomic Energy Commission support ended and of new work in district mapping, regional and topical studies, and appraisal of domestic resources.

In 1960 the Branch of Radioactive Materials was established to gather and focus the uranium and thorium studies scattered through the Geological Survey. A reorganization in 1969 changed the Branch to a Section within the Branch of Rocky Mountain Mineral Resources. With the coming energy crisis foreseen in advance of the Arab oil embargo, the Geological Survey in 1972 established the Office of Energy Resources and the Section became the Branch of Uranium and Thorium Resources in that office.

The Branch in 1974 increased its professional staff from 19 to 24 and its budget to $1.3 million. In addition there were others in other parts of the Geological Survey contributing to uranium studies, and in March 1974 there was a total of about 41 full- or part-time geoscientists employed, having an aggregate of about 425 man-years of uranium geoscience experience. By mid-1974, with a budget increase to $4.2 million, the Branch expanded to 56 full-time scientists and some 30 support personnel to handle geologic and geochemical studies, and the program added an additional 25 personnel in a newly formed uranium-geophysics group. As of fiscal year 1979, the program budget had increased to $6.3 million, with an added $4.5 million contract support from the Department of Energy for participation in the National Uranium Resource Evaluation program, and about $0.8 million from the Bureau of Indian Affairs for resource studies of Indian lands. Funding in fiscal year 1980 decreased overall about $2 million as work on the Department of Energy program was reduced (fig. 2). Since 1939, about 300 Geological Survey professionals representing a total of about 1,600 man-years experience have contributed to various phases of the nuclear-fuel resources investigations.

Program structure

With the expansion in 1974, the program truly became multidisciplinary in scientific approach and national in scope. The Branch of Uranium and Thorium Resources is at the center of the program, and has about 55 professionals working in geology and geochemistry. But much needed expertise, especially in such fields as geophysics, isotope geochemistry, experimental mineralogy, regional geology, paleontology, and resource assessment lies in other Branches of the Geologic Division, and formal projects in those Branches constitute part of the program. In the basic research program, 42 professionals on full- or part-time basis conduct uranium- and thorium-related investigations through program funding to the Branches of Petrophysics and Remote Sensing, Electromagnetics and Geomagnetism, Regional Geophysics, Experimental Geochemistry and Mineralogy, Isotope Geology, Global Seismology, Alaskan Geology, Eastern Environmental Geology, Western Environmental Geology, Paleontology and Stratigraphy, and the Office of Resource Analysis. In the contract work on the Department of Energy National Uranium Resource Evaluation

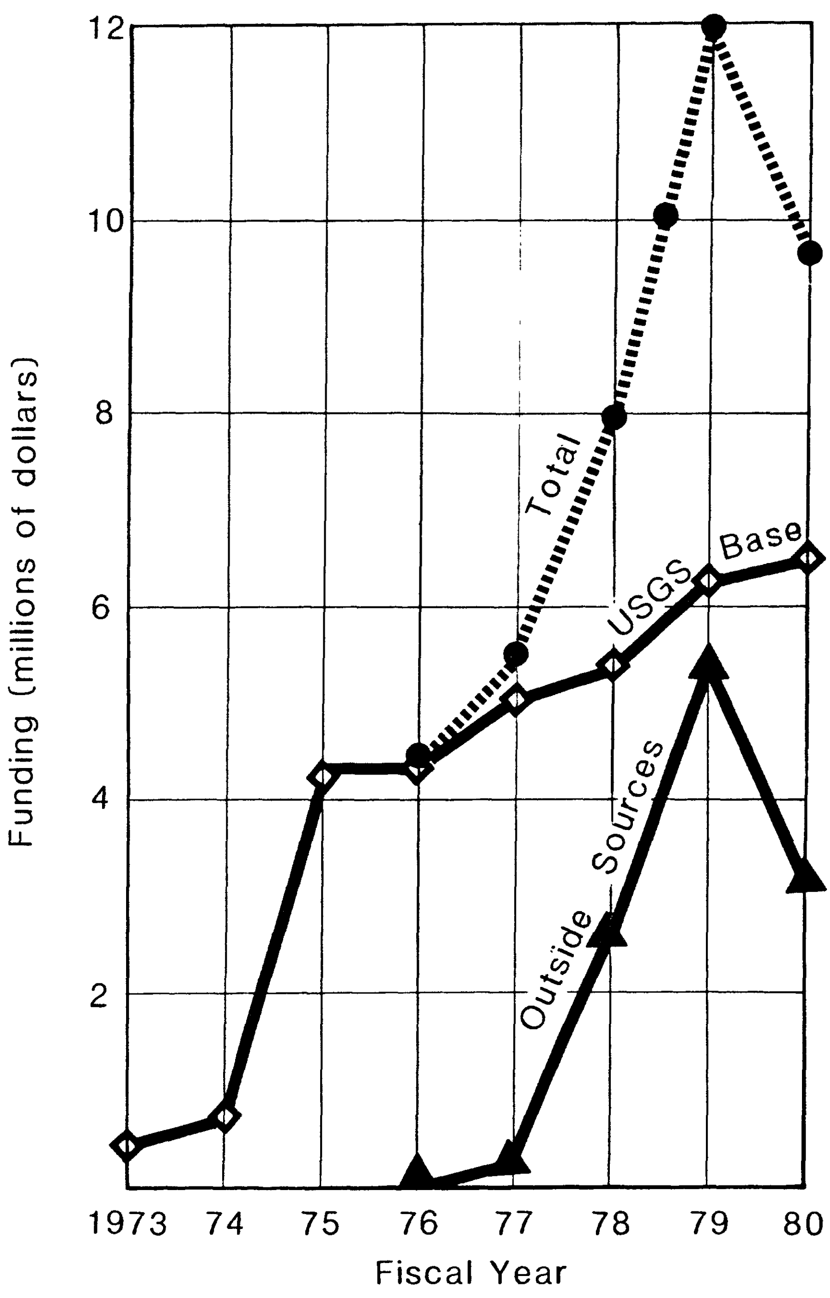


Figure 2.--Amount and source of funding.

(NURE) program, beyond the involvement by the Uranium and Thorium Resources Branch, another 23 scientists of the Branches of Central Environmental Geology, Central Mineral Resources, Western Mineral Resources, Exploration Research, Chemical Resources, and Analytical Laboratories engage in uranium-related investigations. In all, the uranium-thorium program involves about 125 scientists and a similar number of technical and clerical support personnel working full time or part time in 18 Branches of five subdivisions of the Geologic Division.

Much work is still concentrated in the areas of major uranium resources in sandstone environments, but increasing efforts are being directed to other sedimentary areas and especially to promising igneous and metamorphic areas. Figure 3 shows the nationwide distribution of research projects in uranium and thorium. It includes four field and related studies being conducted by university professors and graduate students as part-time researchers in the program and four field investigations being done on contract by State Geological Surveys. It does not reflect seven university-grant studies which are dominantly laboratory work and does not show the 23 large areas being evaluated for uranium favorability for the Department of Energy. Projects are designed to fit both basic and applied research objectives. Experience shows that even those projects on aspects of uranium geology which might commonly be thought of as basic research, in fact typically and quickly produce results of direct practical application in explaining and exploring for uranium deposits.

The program is structured in six research elements, plus the Department of Energy uranium evaluation. Each program research element is a scientific-discipline coordination area, and has assigned personnel working in appropriate projects. Work in uranium districts and promising areas commonly involves several persons from different program elements working in a multidisciplinary approach to the scientific problems. The seven program elements are listed below. Figure 4 shows the allocation of human and dollar program resources to each element. A description of each element follows.

Uranium geochemistry and mineralogy
Uranium in sedimentary environments
Uranium in igneous and metamorphic environments
Geophysical techniques in uranium and thorium exploration
Uranium resource assessment
Thorium investigations and assessment
NURE quadrangle favorability evaluation

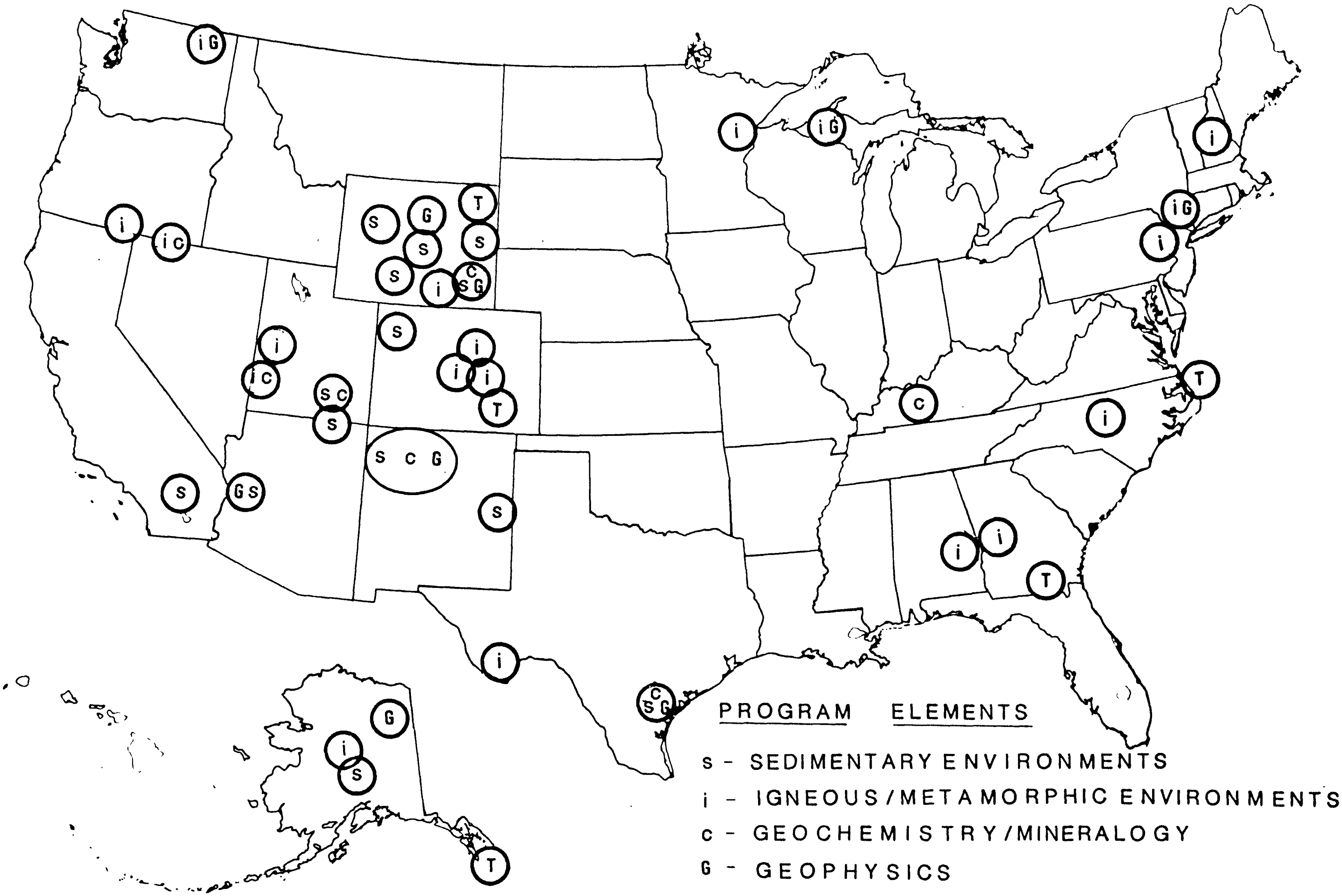


Figure 3.--Locations of research projects, by program element.

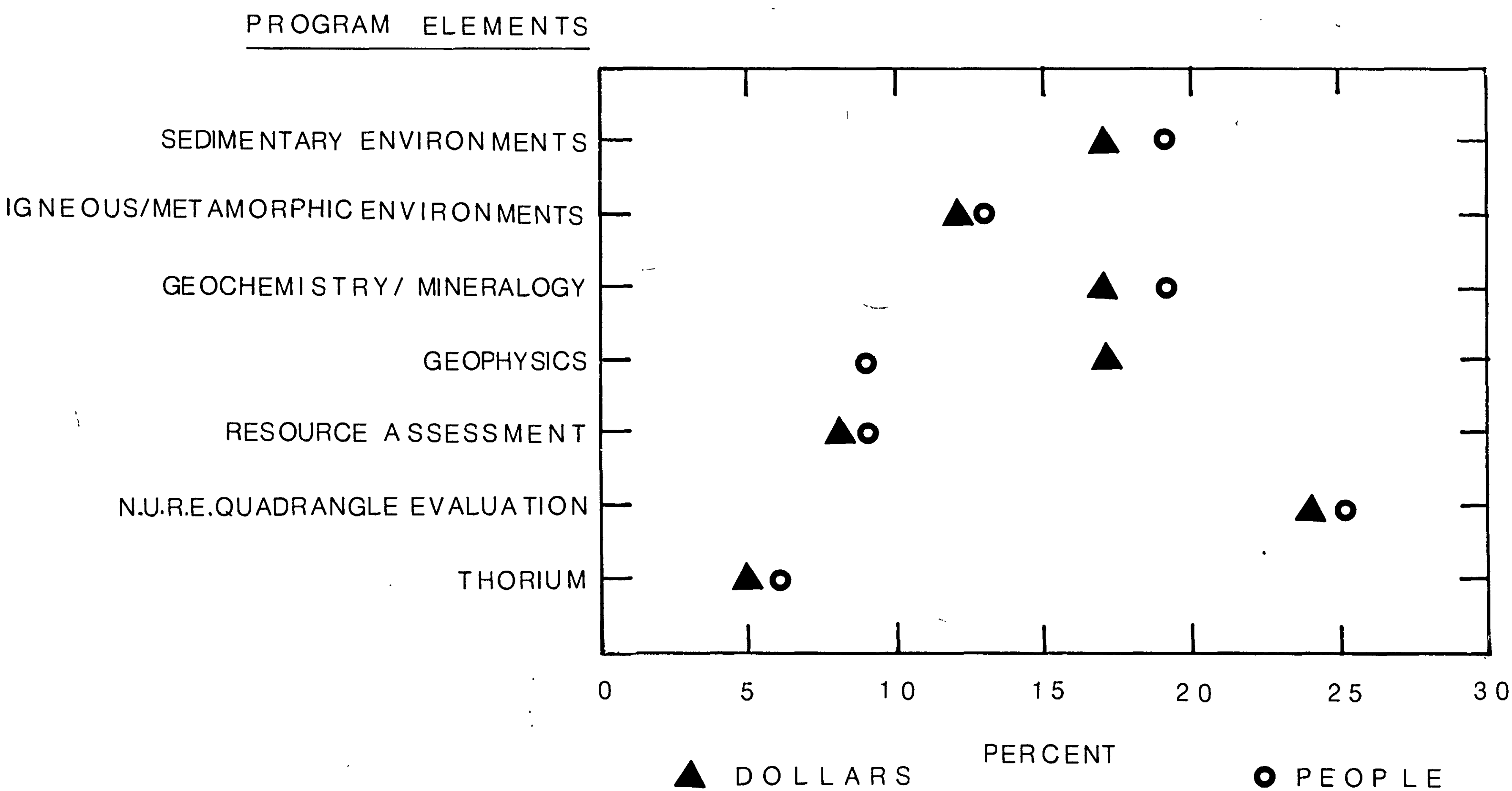


Figure 4.--Allocation of human and dollar resources, by program element.

RESEARCH PROGRAM ELEMENTS

Uranium Geochemistry and Mineralogy

As geologic studies are improving, our understanding of ore-deposit habitat and controls on mineralization, and geochemical and mineralogic studies are improving understanding of how the deposits formed--that is, the processes and the sequence in which they acted to form the deposit. Because the ore-forming processes are generally no longer active today in the mineralized areas, 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 as tracers of fugitive chemical processes which acted in the geologic past, and to determine such things as temperature of chemical reactions and whether ore formation was related 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 granite 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 are the predominant present national uranium resource 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 studies of stratigraphy, sedimentology, subsurface data, and detailed studies of ore deposits in order to determine the sedimentologic framework and environments of deposition of sedimentary rocks which 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. Interpretations critical to determining whether sandstones are favorable for uranium deposits turn on such subtleties as whether the sands were laid down by meandering or braided streams, or 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, and these, in turn, change along or across fluvial-channel deposits, so that the precise conditions and environment of deposition are essential to determine. On the broader scale of understanding the framework of a whole basin, the investigators must define where the sediments came from, under what energy conditions they were deposited, and whether structures were present during deposition to control sedimentation or occurred afterward possibly to affect the migration of uranium-bearing ground water. The sedimentary habitat studies may be abetted by geophysical studies which reveal the third dimension of structure and stratigraphy, and by geochemical studies which 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 quartz-pebble conglomerates of Precambrian age. The potential for such deposits in the United States has only recently become appreciated. In particular, little has been published on the veinlike deposits, and many questions exist concerning the habitat and origin of these deposits which 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 between the not-yet-understood type areas in Australia and Canada and selected study areas in the United States, especially in the Great Lakes region.

The understanding of quartz-pebble-conglomerate occurrences and contained uranium deposits is considerably greater than for 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 granite in what kinds of settings are favorable for providing uranium to surrounding country rocks or for themselves containing 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 beryllium tuffs in Utah. These deposits are being studied in order to define the settings for mineralization and the general favorabilites of the environments.

The favorability and rather preliminary studies described above are precursors of planned studies of fundamental questions of habitat, age, and mineralizing processes. For example, it is not certainly known whether the rich unconformity-related deposits must be of Precambrian age. If they can be younger, that is, if the Precambrian was not 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, petrogenesis studies involving petrology and geochemistry will be extensively pursued. In such studies, it will be necessary, to examine and sample the archetype 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 within an understanding of the geologic setting and timing of events which 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 Colorado Front Range, and volcanic environments of the Basin-Range province. A major part of the research is sponsored by the Department of Energy 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 sand channels, facies, intrusive bodies, rock contacts, 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, electromagnetic 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 the area being assessed, and 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 is 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 on 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 from major ore districts and whether these data show a reliable relationship between measured geologic parameters and the presence, size, and grade of uranium deposits. Even if resource assessment proves always to be a subjective judgment, there seems little doubt that the masses of geologic information being collected on uranium deposits and on geologic environments of apparent potential will provide a more reliable and credible framework within which to render 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 plutons. In 1978-1979 estimation of thorium resources, sponsored by the Department of Energy, dominated activities of the program element.

ACCOMPLISHMENTS IN 1977-79

Uranium geochemistry and mineralogy

Considerable progress was made toward understanding the nature and origin of the roll-type uranium deposits that contain most of the ore in Wyoming and south Texas districts and are common elsewhere. Detailed study of sulfide minerals by M. B. Goldhaber and of magnetic minerals by R. L. Reynolds showed differences among deposits from different regions and defined criteria for deciphering complex, multiphase histories of the geochemical processes that formed the deposits. In Texas deposits, uranium is associated with clays and titanium-rich mineral phases formed during alteration. In Wyoming deposits, the same association is found but uranium also resides in uraninite and other opaque mineral phases associated with vanadium and selenium. Each deposit shows at least two distinct stages of sulfide-mineral formation. The earlier stage typically involves pyrite replacing iron-titanium oxide minerals as a necessary precursor to mineralization. The later stage involves marcasite accompanying the formation of ore. This work also led to laboratory experiments by Goldhaber which demonstrated the mechanism and chemical-environment conditions of inorganic oxidation of pyrite. This oxidation is a necessary part of the ore-forming process and has generally been ascribed to organic processes involving either carbonaceous material or bacterial action. In south Texas, fault-leaked H_2S may have entered host sandstones, causing formation of a third generation of iron sulfides and producing rereduction of iron oxides which destroyed the original contrast of oxidized and reduced ground on opposite sides of roll-type deposits. If previously oxidized ground, now in a reduced state, cannot be recognized, a major criterion for exploration is removed. Investigation of sulfur isotopes by R. O. Rye showed that the isotope values are distinct on opposite sides of deposits despite post-mineralization rereduction. The sulfur isotopes also indicate that the processes active in rereduction to form sulfides can be traced to the fault which leaked H_2S into the ore-bearing sandstone and cannot be related to present-day ground water.

Roll-type deposits were simulated in a computer model by C. G. Warren and H. C. Granger. In the model, ground water carrying dissolved oxygen flowed through a confined sandstone layer containing pyrite. The oxygen destroyed the pyrite on contact and created a crescent-shaped alteration zone resembling a classic roll-type deposit. The model permits examination of the effect of changes in velocity of ground-water movement and the monitoring of transverse dispersion of oxygen. The effects of clay layers or other impermeable barriers in the sandstone also can be simulated. Some conclusions are that the regularity of the oxidation front is an indication of the importance of oxygen diffusion to the ore-forming process, and that the numerical relation between shape and either channeled ground water flow or oxygen leakage across aquifer boundaries offers a basis for calculating ground-water velocities.

A sandbox model was constructed by D. K. Sunada and F. G. Ethridge (Colorado State University) to evaluate effects of introducing humic acid into sand saturated with aluminum-potassium sulfate solution. Precipitation reactions and simulated ground-water flow patterns were observed under changing conditions of flow and sand layering, and using baffles to represent mudstone lenses. Solution boundaries which formed as humic acid was precipitated provided excellent analogs of roll-type deposits. Increasing flows caused the precipitate to be dissolved and then redeposited at a new interface, simulating the commonly presumed migration downdip of roll-type uranium deposits. Decreasing flows caused precipitation at multiple fronts. Study of the actual flow and precipitation mechanisms showed the effects of pore filling, hydraulic conductivity, flow convergence around baffles, and time of contact between solutions. Results indicate that observed characteristics of roll-type uranium deposits can be used to infer paleo-ground-water flow conditions.

Electron-microprobe analyses of uraninite and coffinite by R. I. Grauch indicate that uraninite is not simple uranium oxide but contains essential calcium and silicon, and that the uranium silicate, coffinite, also contains essential calcium. This discovery helps to explain the observed interrelation of the two minerals in many deposits and points toward experiments to define the physicochemical conditions of ore formation. Timing of ore deposition also is indicated by petrographic examination of samples from a Utah deposit. Coffinite fills cells in plant material and apparently was deformed in place as the plant material was compacted during and just after burial.

A study by K. R. Ludwig of uranium-lead isotope apparent ages of uranium ores from the Gas Hills and Crooks Gap, Wyo., districts showed that mineralization occurred sometime in the interval 55 to 26 million years (m.y.) ago. The latest mineralization is firmly established as being no later than Oligocene, which ties to other assumptions concerning paleoclimatic conditions desirable for ore formation (such as a warm, humid, highly oxidizing environment). Other work showed the significance of initial radioactive-daughter disequilibrium and the possibility of errors it causes in dating young (<39 m.y.) ores.

Carbon analysis by J. S. Leventhal showed that organic material associated with two tabular ore deposits from the Grants, N. M. district varies isotopically with grade of ore material. Organic carbon at the edge of the deposits is isotopically like sedimentary organic matter, but organic carbon in high-grade ore samples is isotopically heavier. It appears that radiation from uranium in the ore causes structural and isotopic changes in the associated organic carbon. The radiation-produced changes make the organic material less soluble and oxidizable, so that it acts as armor to protect the uranium ore from remobilization. Studies of Devonian black shale of the Appalachian Plateau showed a one-to-one relation of uranium and organic carbon. Lateral and vertical changes in distribution of uranium and associated trace elements probably relate to paleogeography and volcanic activity in highlands sediment-source areas.

Laboratory studies of volcanic rocks as potential sources of uranium, by R. A. Zielinski, showed that uranium is released from glassy material by dissolution, the rate controlled by the surface area of the material. In felsites, uranium loss occurs at variable rates controlled by the ways in which uranium is present in mineral structure or loosely bonded to mineral surfaces. After initial rapid loss of readily soluble uranium, felsite is a poorer source than volcanic glass. Related studies suggest that uranium content of secondary silica in veinlets within volcanic ash is an indicator of uranium release from the volcanic material and of concentration of uranium in ancient ground water.

J. S. Stuckless studied granites which are likely sources of uranium. Common characteristics of apparently fertile granites were defined so that a suite of distinctive petrologic type could be identified. Isotopic studies of the Granite Mountains, Wyo. indicate a huge loss of uranium during erosion of the uplifted mountain area. Calculations suggest that much more uranium was lost from the source rocks than has been found to date in deposits of the adjacent basins into which the material was shed to form sedimentary rocks. These source rocks are part of a uranium-rich Precambrian province, and any sedimentary rocks derived from them during late Precambrian to Tertiary time may have potential for uranium deposits.

Research and application studies of geochemical-exploration techniques and approaches produced both basic scientific information and results immediately useful to the uranium industry. High-sensitivity helium-detection equipment designed by G. M. Reimer was used in analysis of subsurface waters sampled around uranium areas near the Black Hills, S. D. Because uranium is not readily taken into solution in reducing environments below the water table, the water samples contain little uranium and are not anomalous by standard chemical analysis. Helium, however, is a product of radioactive decay of uranium independent of chemical-solution processes and is readily detectable in the water samples to indicate the presence of nearby uranium.

Ratios of thermoluminescence values from two temperature ranges were determined by C. S. Spirakis for quartz and feldspar grains from opposite sides of a roll-tye uranium deposit. Values from the oxidized side are completely distinct from values on the reduced side and suggest that the deposit migrated downdip, causing mineralogic radiation effects as it moved. The techniques may be useful in locating mineralized veins or other ground which has been leached of uranium at the surface.

The use of stream sediments and surface water for geochemical sampling in the search for uranium was investigated by K. J. Wenrich-Verbeek. The scavenging effect of organic material was shown to be many times more effective than that of iron and manganese oxides or clays in adsorbing uranium to produce possible geochemical anomalies. Contrary to theoretical considerations, phosphate in natural waters having a normal range of acidities does not complex with uranium. An exploration application study in New Mexico suggested that Precambrian quartzite and pegmatites are sources for soluble uranium detected in spring water. In continuing studies on the occurrence of uranium and radium in spring water, J. K. Felmlee and R. A. Cadigan found clues to subsurface chemical processes in the analysis of data for 116 springs in eight western states. For example, the correlation of radium and conductance suggests control of ionic strength on solubility of salts with which radium can coprecipitate. A correlation of uranium and temperature is probably related to the complexing of uranium with bicarbonte, which is more soluble in cold water. Radon and radium values in spring water were used to make inferences as to the amount of uranium in the nearby subsurface to produce the observed amounts.

Uranium in sedimentary environments

In the San Juan Basin of New Mexico, M. W. Green has demonstrated a subtle disconformity below the Westwater Canyon Member and laterally equivalent parts of the Morrison Formation of Jurassic age. The units above the disconformity were deposited in a high-energy fluviolacustrine environment, and the units below were deposited in a sabkha-eolian environment. Uranium deposits are known only from fluvial sandstone beds above the disconformity. Stratigraphic studies of the Cretaceous rocks by A. R. Kirk delineated a pattern of transgressive and regressive sequences and indicated a need to reinterpret the depositional history and correlations of the marine and nonmarine Cretaceous sequences. Part of this reinterpretation was done by R. E. Thaden for the Dilco Coal Member of the Crevasse Canyon Formation, and it shows a regional pattern and direction of prograding sedimentation. Eastward, stratigraphic and sedimentologic studies by J. L. Ridgley provided a start at redefining the sequence in the Chama Basin and correlating it with units of the San Juan Basin. Study of the Ruby Well No. 1 mine by J. F. Robertson showed that the distribution of ore in the roll-type body is related to sandstone texture and permeability, and that the alteration originally associated with the ore has been modified by later ground-water movement and oxidation.

On the Colorado Plateau, J. A. Campbell found that uranium in the Cutler Formation of Permian age is limited to small fluvial sandstone bodies in a sequence of shales and sandstones of marine and eolian origin. Ore appears to be much younger than the host rock but is different in petrology, habit of occurrence, and trace elements from ore in the younger Chinle and Morrison rocks, and so it may represent a distinctive episode of mineralization. Studies of the Chinle Formation by R. D. Lupe showed that uranium deposits occur in rocks deposited in low-energy, distal environments as part of a regional fluviolacustrine sequence. Mineralization may have been controlled by overlying sandstones of a braided-stream environment. Fred Peterson observed that uranium deposits of the Henry Mountains mineral belt, Utah, occur in sandstone beds closely associated with dark-gray mudstone beds deposited in offshore lacustrine environments. The mudstones are thin and poorly exposed, but their postions can be inferred projecting in an offshore direction from better exposed marginal lacustrine sandstones. Companies appear to be using the indicated association of ore and mudstones to guide exploration.

Studies in the Powder River Basin, Wyo., by E. S. Santos suggested that sediments were introduced from the south and west and that ore deposits occur where sandstone-mudstone ratios in the Wasatch Formation are in the range from slightly more than 1.0 to slightly less than 0.5. Ore deposition tended to favor sandstone units that extend from the high-energy facies into areas of mostly shale and siltstone. Because favorable horizons dipping into the basin do not contain ore deposits below a certain depth, it is possible that facies and depth combine as controls on ore deposition. H. W. Dodge, Jr., working on Cretaceous rocks of the Powder River Basin, has found that significant uranium occurrence is confined to organic-rich sandstone and siltstone interbedded with claystone. These rocks were laid down in estuarine and tidal-flat environments. This study also suggested a depth limit of mineralization, apparently much shallower in the northern part of the basin than in the southern part. At Copper Mountain, Wyo., uranium deposits in sedimentary rocks are indicated by R. E. Thaden to be confined largely to an east-west-trending graben, 3 to 8 km wide along the south side of Copper Mountain. Organic matter was available, but an additional possible reductant of uranium was petroleum fluids leaking upward along the graben boundary fault. Mapping by D. A. Seeland showed that paleostreams draining granite highlands into the

Wind River Basin in Tertiary time and which along their channels formed the host rocks for many uranium deposits, are marked by modern streams flowing along the same paths. Thus, major present-day drainages may be guides to paleostream-deposited rocks favorable for uranium deposits.

Studies in Colorado by L. C. Craig resulted in recognition of two thick lobes of sandstone in the Burro Canyon Formation that extend beneath the southwest margin of the Piceance Creek Basin and are potentially favorable host rocks for uranium deposits. In Alaska, the Tertiary sedimentary basin sequences generally appear favorable for uranium, but until recently no anomalous uranium occurrences had been found. Industry exploration has now revealed a few concentrations in sedimentary rocks, and K. A. Dickinson has found others. Most of the uranium found so far appears to be uneconomic and related to siderite-rich horizons or oxidation-reduction interfaces in sandstones, but at least epigenetic mineralization is now documented.

The Basin-Range Province is uranium-exploration frontier country. J. K. Otton has developed a model to explain ore deposits in the Date Creek Basin, Ariz., that may be applicable to other basins having similar settings. Host rocks are late Eocene-early Miocene in age, and uranium deposits are in a transition zone between fluvial and lacustrine facies. Tectonic movements during basin filling restricted the lacustrine environment, and the lakes received much tuffaceous sediment of anomalous uranium content from nearby volcanic sources. Uranium was leached from volcanic material and moved in solution to be precipitated where it came in contact with carbonaceous lacustrine sediments. Reconnaissance by C. S. Bromfield in three other basins suggests that lacustrine beds with volcanic material nearby, and evidence of silicification in host rocks, are important aspects of the uranium-mineralization picture in the Arizona Basin-Range area. Similar habitats, as well as the presence of basin-fill sandstones and conglomerates and vein deposits in Tertiary igneous rocks, were noted by C. T. Pierson and M. W. Green in the Marfa Basin of southwest Texas as indicating significant potential for uranium deposits.

Christine Turner-Peterson recognized the importance of an apparent association of lacustrine mudstones and uranium, based on studies of the Newark, Gettysburg, and Hartford Basins in the eastern United States. An hypothesis was proposed: In a zone of intercalated nearshore lacustrine sandstone and offshore lacustrine mudstone, humic and fulvic acids would be expelled shoreward from compacting mudstones, and where these fluids met uranium-bearing ground water moving toward the lake, uranium precipitation would occur. Alternatively, humic acid could seep into the nearby sandstones and become fixed as tabular humate bodies like those in Colorado Plateau sandstone, and then catch uranium from ground water moving through the sandstones. Work by Fred Peterson, R. H. Tschudy, and S. D. VanLoenen indicates that lacustrine mudstones containing palynomorphs generally yield a stain of humic material. Mudstones associated with the uranium host rocks of the Colorado Plateau contain palynomorphs but no humic acid. It is believed that the palynomorphs indicate that humic acid was once present and is now absent because humic material migrated from the rocks as proposed in the hypothetical model. An adjunct of the model is that under the pH (acidity) conditions which would be likely at the mudstone-sandstone interface, iron and aluminum hydroxides on clays would have carried positive charges, attracting and precipitating organic ions expelled from the lake muds. The organic material subsequently precipitated the uranium.

Uranium in igneous and metamorphic environments

The economically most significant results in crystalline-rock studies were from work in three areas of ancient Precambrian quartz-pebble conglomerates. F. A. Hills reported that the Estes Conglomerate in the Black Hills, S. D. is radioactive, gold bearing, pyritic, and associated with an iron-formation, very much like major uraniferous conglomerates in Canada and South Africa. Lead isotope determinations and thorium-uranium ratios suggested that uranium has been leached from the surface and could exist in economic quantities downdip. Companies have claimed the area and begun exploration. Similar results were reported from work supported at the University of Wyoming. Several new localities showing considerable strike length of anomalously radioactive conglomerate were found during mapping of the Sierra Madre Range, south-central Wyoming. Uranium values at the surface were significant, and the conglomerate should be richer below ground. The report sparked new industry activity.

Several studies in the Precambrian shield area of Michigan indicated potential for uranium deposits in a variety of different settings. Reconnaissance studies by M. R. Brock showed that lower Precambrian granites and gneisses of the region are three to five times as radioactive as similar rocks of younger Precambrian age in Michigan. Thus, ample uranium would have been available during weathering or later supergene mobilizing episodes to form deposits as veins or shear-zone fillings in the basement rocks, analogous to giant deposits known in Canada and Australia. Also, uranium would have been available to concentrate in Precambrian quartz-pebble conglomerates and quartzites which cover part of the basement and were derived from it. In particular, the study showed high radioactivity (both uranium and thorium) in quartzite which makes up part of the Goodrich Formation. J. Kalliokoski studied the Jacobsville Sandstone of probable late Precambrian age and found quartz-pebble conglomerate at the base and higher within the formation. These materials were derived from a deeply weathered source terrain from which uranium was probably released readily. The Jacobsville unconformably overlies metamorphic basement in a setting like that of the area containing major uranium deposits in Saskatchewan, and a few occurrences of uranium in the basement have been reported near the edge of the Jacobsville. In paleocurrent studies in the upper peninsula of Michigan, R. W. Ojakanges found that much of the quartz-rich Precambrian clastic sequence that overlies metamorphic basement was transported from anomalously radioactive granite terrane to the east and southeast.

Studies of the Midnite mine of northeast Washington by J. T. Nash suggested that the uranium in the Precambrian metamorphic host rocks was hydrothermally introduced from a granitic pluton intruded into those rocks in Cretaceous time, but that supergene processes later concentrated the uranium into ore deposits. This sequence was confirmed subsequently by lead-uranium age determinations by K. R. Ludwig. The pluton is 76 m.y. old, and the uranium ore is 51 m.y. old. Fission-track studies showed that high temperatures had not been experienced by the pluton after its intrusion, indicating that the concentration of ore 51 m.y. ago took place in a relatively cool, supergene environment. Nash found that plutons in the area showed fertility for uranium if they were mica bearing and were much less fertile and not likely to have been sources of uranium if they were hornblende bearing. The micaceous igneous rocks contain uranium in magnetite, biotite, and possibly uraninite. The hornblendic rocks contain uranium in sphene, zircon, and allanite, from which it would be much harder to release.

Preliminary study of the Pitch mine, Colo., by J. T. Nash indicated that ore zones in the Leadville Limestone occur where the host has been dolomitized and are associated with limonitic gossans from which the uranium has been leached. Other ore is in sandy and coaly rocks of the Belden Formation. Mineralization occurs along and near a major reverse fault. Mapping of that district by J. C. Olson indicated that volcanic tuffs probably ponded along an escarpment of the reverse fault and may have provided a source for the uranium.

A significant occurrence of uranium minerals in two-mica granite of the Lake Sunapee, N. H. area was described by E. L. Boudette. That granite is part of the westernmost of three belts of similar granite. New age determinations indicate that the granites correlate in time with major uranium-bearing granites of France, and the New England plutons appear to have a tectonic setting like those in France, suggesting criteria to be incorporated in a model of granitic habitat for uranium. Follow-up area studies have indicated new aspects of structure and the timing of geologic events in that part of New England which may necessitate a serious reappraisal of older ideas of the geology.

D. A. Lindsey showed that the Spor Mountain, Utah, volcanic sequence consists of four groups differing in character and age and separated by unconformities. Uranium and beryllium deposits known so far are exclusively associated with the third group, but the fourth group may also have potential for uranium deposits.

Quartz porphyry intrusive bodies, locally very radioactive, were found by T. P. Miller in interior Alaska. Purple fluorite and a secondary uranium mineral (indications of secondary concentration of uranium generally are lacking in crystalline rocks of Alaska) were found at one locality. Anomalously radioactive alkaline dikes were found by Miller and B. R. Johnson in the southeastern Seward Peninsula. The uranium is largely in allanite, probably associated with metasomatism of the syenite wallrock.

Geophysical techniques in uranium and thorium exploration

Results particularly significant for uranium exploration were obtained in test applications of nonradiometric geophysical field methods. B. D. Smith demonstrated, for a tabular ore deposit in Utah and a roll-type deposit in Colorado localized in fluvial channels, that surface magnetic and induced-polarization measurements are effective, rapid, and inexpensive exploration tools. Subsurface channels can be delineated as drilling targets in both of those areas because they carry either more or less magnetic minerals than surrounding rocks. Geophysical contacts coinciding with possibly mineralized zones show in induced polarization surveys because the mineralizing process commonly changes the amounts and kinds of sulfide and clay minerals in the host rock near the orebody. The survey techniques and subsequent interpretations may be sharpened through use of laboratory measurements of magnetic and electromagnetic properties of rocks from the survey areas.

Field surveys at the Camp Smith mine, New York, by D. L. Campbell, using magnetic, electromagnetic, and radiometric methods, showed that uranium and sulfide minerals are related in occurrence along a particular rock-unit contact. These observations added confirmation to a proposed model of origin of uranium deposits in the Precambrian of the Hudson Highlands-Reading Prong.

Continued testing of drill hole geophysical measurements by J. H. Scott demonstrated further that resistivity and induced polarization measured with a transmitter in one hole and a receiver in another hole can define geophysical/geochemical anomalies that may be present between the holes. This discovery has major implications in reducing the number of exploration drill holes needed. Considerable effort was devoted to development of a temperature-stable magnetic-susceptibility probe and a vertical fluxgate magnetometer probe to detect alteration around orebodies as enlarged targets for exploration. Development work also progressed well on a digital induced-polarization logging system and a hole-to-hole acoustic pulse transmission system. G. R. Olhoeft's laboratory measurements on rock and mineral samples showed that nonlinear complex resistivity effects related to specific chemical reactions can be measured when electrical currents are high. Olhoeft and Scott found that a combination of a logging tool and equipment from the laboratory permitted such measurements in drill holes. The method has promise for delineating specific geochemical environments associated with uranium deposits or altered zones around them.

F. E. Senftle and A. B. Tanner developed a prototype drill-hole logging device which measures low-energy gamma rays not usually detected by logging tools. The device provides a direct assay of uranium in place and at the same time gives a measure of disequilibrium between uranium and its daughter products. This probe is relatively inexpensive to use and does not require a radioactive source element.

J. S. Duval designed and built an aerial gamma-ray survey system using a plastic scintillator as a detector instead of a fragile sodium-iodide crystal. The system worked well in flight tests and was immediately added to the arsenal of Geological Survey geophysical tools being applied routinely to Wilderness-survey and uranium areas.

Remote-sensing studies conducted by G. R. Raines, using LANDSAT images of the Powder River Basin, Wyo., showed that computerized image enhancement permitted remote mapping of surface alteration associated with uranium mineralization. Vegetation patterns in a specially processed color ratio of LANDSAT data revealed underlying rock facies and structure which cannot be mapped geologically at the surface and which appear to be related to known ore occurrence.

Uranium resource assessment

This program element was established in mid-1977. A major priority was the creation of a computer data bank containing standardized information on all significant uranium occurrences in the United States. New personnel and equipment were acquired, and the data bank was brought nearly to completion by the end of 1979. A synopsis of literature on every uranium deposit in the world was prepared by V. P. Byers. R. B. McCammon of the Office of Resource Analysis formulated a plan to use multiple regional geologic data sets and grade-tonnage information on ore deposits to produce a relatively objective, quantitative assessment of uranium resources. Because resource assessment is highly dependent on an understanding of geologic habitat and origin of uranium deposits, W. I. Finch organized an effort by many geologists in the program to construct conceptual models of occurrence for 15 different types of deposits. These models were well under way at the end of 1979 and will serve as a basis for designing logic circuits and selecting weighting factors in dealing with geologic information for resource assessment.

Thorium investigations and resource assessment

The most noteworthy accomplishment of thorium studies was assessment of the major known thorium resources of the United States, done by M. H. Staatz, T. J. Armbrustmacher, and others and funded by the Department of Energy. This assessment indicated much larger potential resources than previously considered. It covered the important Lemhi Pass, Idaho, vein district, the main placer thorium deposits, carbonatite-related deposits, and disseminated deposits. Tonnage numbers for the disseminated deposits were in a fairly speculative category because of the need for more detailed geologic information and because no production has occurred from such deposits. Nevertheless, the preliminary calculations indicated that these newly considered deposits contain the bulk of known potential thorium resources in the United States. The cost at which such resources might be extracted has not been firmly established. A follow-up assessment of lesser resources was begun in 1978 and is still underway.

INTERACTION WITH OTHER AGENCIES, INSTITUTIONS, AND COUNTRIES

The broadest interaction with another Government agency is with the Department of Energy. In the support of the Department of Energy National Uranium Resource Evaluation (NURE) program, the Geological Survey is proceeding in directions decribed in more detail in the program-element section: favorability evaluation in 23 National Topographic Map Series (NTMS) $1^{o}x2^{o}$ quadrangles; favorability studies in areas which may have the right non-sandstone settings for major types of uranium deposits; development of deposit models and data-analysis methods by which to improve resource assessment; and assessment of the Nation's thorium resources. This work is carried out under an interagency Memorandum of Understanding, with policy established in Washington D.C. by the two agencies and details of the cooperation arranged at working levels by a Department of Energy Grand Junction-Geological Survey Denver committee. Working groups of this committee consider ways to coordinate activities in aerial surveys, drilling, geologic mapping, and topical studies so as to serve best the objectives of both agencies.

Geologists from the uranium-thorium program from time to time are called on to take part in mineral-resource evaluations of proposed wilderness areas and other Government-managed lands, in behalf of the U.S. Forest Service, U.S. Bureau of Land Management, or U.S. Bureau of Indian Affairs. A significant program of varied activities aimed at helping the Navajo Nation evaluate its uranium-resource potential has recently been introduced. Program scientists also commonly participate in environmental-impact studies related to actual or proposed uranium-industry activities. A recent example is the Geological Survey's work in the major Department of Interior environmental-impact assessment of the assumed expansion of uranium mining in the San Juan Basin, N. M.

In some areas, uranium-related studies may best be conducted by local experts of State Geological Surveys. Contract geologic investigations as part of the Geological Survey's uranium-thorium program at the time of writing (mid-1979) are being conducted by the Alabama Geological Survey, the Arizona Bureau of Geology and Mineral Technology, the Georgia Geologic and Water Resources Division, and the Pennsylvania Topographical and Geological Survey.

Cooperative work with uranium experts of other countries mostly takes place through the International Atomic Energy Agency. This work includes research on uranium in granite, remote-sensing studies of major uranium areas in Canada, Australia, and the United States, and participation in working groups to produce handbooks on aerial radiometric surveying and on remote sensing for uranium exploration, and to examine basic aspects of uranium research. In addition, the Geological Survey participates in the Global Exchange and Processing of Information on Chemistry (GEPIC) program of the International Geological Correlation Program (IGCP), which collects data on the chemistry of granite and categorizes granite with respect to fertility for uranium.

OPPORTUNITIES FOR EXTERNAL PARTICIPATION

To help attain the objectives of its various programs, the Geological Survey is authorized by Public Law 85-934 to spend funds through grants for the support of scientific research and for other purposes. Grants may be awarded only to colleges and universities, other non-profit organizations, and State and local governments. They are based on unsolicited research proposals submitted by investigators who believe that they can contribute to an ongoing scientific program conducted by the Geological Survey. Research proposals may be submitted to the Survey at any time, but some programs will consider only those proposals submitted in response to a public announcement of a project to be carried out partly or exclusively through research grants.

Opportunities for grant-supported research projects related to the uranium-thorium program depend on the nature and scope of the proposed work, its importance to the program, and the availability of funds. Proposals that complement, rather than duplicate or overlap, existing or planned Survey-conducted projects on uranium and thorium resources have a better chance of receiving support. A prospective grantee may discuss his proposal with appropriate staff members in the Branch of Uranium and Thorium Resources before formally submitting it to the Geological Survey.

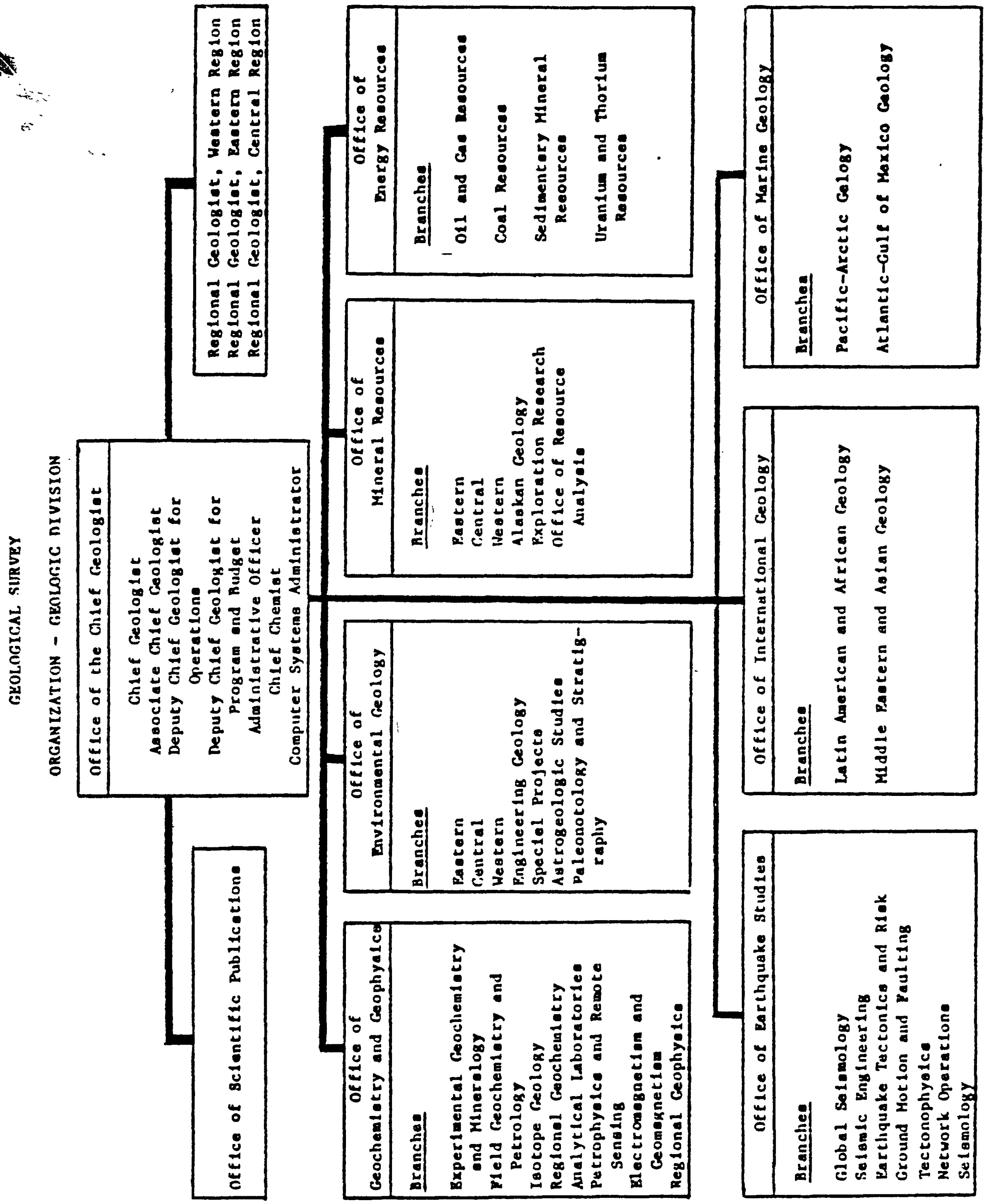
Detailed information about the procedures for applying for a research grant are contained in a Geological Survey pamphlet entitled "Grants for scientific research." Copies of this publication may be obtained from any Survey office.

The Geological Survey may award a research contract, as opposed to a grant, to any individual or group, including for-profit organizations, that has the capability to deliver the required product, such as a map, a report, rock or mineral samples, analytical data, or a scientific instrument. A contract usually is awarded in response to a Request for Proposals (RFP), which the Geological Survey issues whenever it requires the services of a private organization. The Survey may send copies of an RFP to known potential contractors, and the RFP also is published in Commerce Business Daily. However, in some circumstances a contract may also be awarded on the basis of unsolicited proposals.

Further information about grants or contracts related to the uranium-thorium program may be obtained from the Branch of Uranium and Thorium Resources, U.S. Geological Survey, Denver Federal Center, P.O. Box 25046, Denver, Colorado 80225.

APPENDIX 1

Organization of the Geologic Division and Branch of Uranium and Thorium Resources, U.S. Geological Survey



ORGANIZATIONAL CHART

OFFICE OF ENERGY RESOURCES
BRANCH OF URANIUM AND THORIUM RESOURCES

Supervisory Geologist GS-15

Associate Branch Chief	GS-14	Editorial Assistant	GS-6
Administrative Assistant	GS-9	Editorial Assistant	GS-5
Scientific Illustrator	GS-9	Administrative Tech.	GS-5
Supervisory Secretary	GS-7	Clerk (Steno)	GS-5
		Clerk (Typing)	GS-5
		Clerk/Typist (3)	GS-4

THORIUM INVESTIGATIONS AND ASSESSMENT

Geologist	GS-15
Geologist	GS-15
Physical Science Aid	GS-7

URANIUM IN IGNEOUS AND METAMORPHIC ENVIRONMENTS

Geologist (2)	GS-15
Geologist	GS-14
Geologist (5)	GS-13
Geologist	GS-9
Geologist	GS-7
Physical Science Technician	GS-8

URANIUM RESOURCE ASSESSMENT

Geologist	GS-15
Geologist	GS-11
Computer Tech.	GS-5
Computer Aid (2)	GS-4

URANIUM IN SEDIMENTARY ENVIRONMENTS

Geologist (3)	GS-15	Geologist (1)	GS-11
Geologist (4)	GS-14	Geologist (1)	GS-9
Geologist (12)	GS-13	Geologist (3)	GS-7
Geologist (6)	GS-12		

URANIUM GEOCHEMISTRY AND MINERALOGY

Geologist	GS-15
Geologist	GS-14
Geologist (12)	GS-13
Geologist (2)	GS-11
Geologist	GS-7
Physical Science Tech.	GS-8

APPENDIX 2

Annotated List of FY 1980 Projects by Program Element with Statements of Objectives

[Numbers in margin refer to project number, Branch of Uranium and Thorium Resources]

Uranium geochemistry and mineralogy (J. S. Leventhal, coordinator):

0179 1. Uranium ore-forming processes (H. C. Granger)--investigate geochemical processes of uranium concentration in low-temperature deposits, particularly relations among uranium, sulfur, selenium dissolved oxygen and humic matter; to develop geochemical models for genesis of sandstone-environment deposits.

1077 2. Geochronology of uranium ores and their host rocks (K. R. Ludwig)--determine ages of uranium ores in vein and sandstone deposits, chiefly by lead-uranium method; investigate lead-uranium systematics and micromineralogy of ores; contribute to models of ore formation, including local and regional timing of mineralization.

1094 3. Organic geochemistry of uranium (J. S. Leventhal)--determine the chemical nature of organic matter associated with uranium and its role in ore genesis or concentration; develop and apply experimental procedures for simulating ore-forming environments and processes.

1423 4. Granite source-rock studies (J. S. Stuckless)--investigate granite as sources of uranium in adjacent sandstone-type deposits and in intragranite veins; elucidate granite histories and crustal evolutionary processes of uranium preconcentration in potential source rocks, and document uranium mobility in such source rocks.

5. Uranium and trace elements in Devonian and Lower Mississippian black shale (Branch of Oil and Gas Resources project) (J. S. Leventhal, M. B. Goldhaber)--establish the relation of uranium and other trace elements to organic matter and sulfides in the Chattanooga Shale, Kentucky and West Virginia, including definition of regional patterns in vertical and horizontal distribution of anomalous uranium values in the shale.

1424 6. Volcanic source-rock studies (R. A. Zielinski)--investigate the derivation of uranium in sandstone-type deposits from volcanic rocks or volcanic components in sedimentary rocks; examine release and mobilization of uranium within or from volcanic rocks in the field and in experimental leaching of volcanic materials.

1427 7. Relation of diagenesis to uranium deposits (M. B. Goldhaber)--establish by mineralogic and isotopic study the relation of diagenetic processes and their geochemical effects to uranium concentration and mobility; study organic and inorganic processes of uranium reduction involving sulfur compounds, integrating laboratory experimental results and field observations.

2428 8. Paleomagnetism applied to uranium exploration (R. L. Reynolds)--determine the character and histories of magnetic minerals associated with sandstone-type deposits, as a means of elucidating the ore-forming processes and deposit histories.

1672 9. Stable isotopes and uranium-ore genesis (R. O. Rye)--study D/H, O^{18}/O^{16}, S^{34}/S^{32}, C^{13}/C^{12}, and CO_2 as indicators of geochemical processes in, and origin of, uranium deposits.

1357 10. Geochemical techniques in uranium exploration (R. A. Cadigan) collect and analyze regional geochemical data on the Colorado Plateau and on uranium, helium, and radon in Colorado.

1368 11. Uranium daughter products in modern decaying plant remains and in soils and stream sediments (K. J. Wenrich-Verbeek)--determine the extent of absorption of uranium on decaying plant material and on different size fractions of stream sediments in different climatic areas; define the utility of these materials as sample media for uranium exploration.

1369 12. Geochemical-halo uranium exploration techniques (C. S. Spirakis)--identify and interpret possible geochemical/mineralogic halos around orebodies in order to elucidate chemical processes of ore formation and establish larger targets for exploration; examine thermoluminescence as a possible new indicator of roll-front deposit migration or halo around deposits.

1375 13. Radium and other isotopic-disintegration trace-element migration in springs and subsurface water (J. K. Felmlee)--study natural radioactive waters as possible indicators of subsurface uranium deposits.

1422 14. Uranium in streams as an exploration technique (K. J. Wenrich-Verbeek)--evaluate and apply methods of surface-water sampling and geochemistry as a means of uranium exploration.

1376 15. Gaseous-emanation detection techniques for uranium exploration (G. M. Reimer)--develop equipment and field measurement techniques to evaluate helium, radon, and other gases as indicators of subsurface uranium deposits.

16. Thermodynamic properties of uranium minerals (Branch of Experimental Geochemistry and Mineralogy project) (R. A. Robie)--compile existing data and conduct laboratory measurements to add new data on thermodynamic properties of uranium minerals, as a basis for understanding the mineralogy and geochemistry of uranium and various temperatures and in various geochemical environments.

17. Microstructure analysis of primary uranium-ore minerals (Branch of Experimental Geochemistry and Mineralogy project) (G. L. Nord, Jr.)--use electron-microscope techniques and other microanalytical methods to determine the structure of ore minerals such as uraninite, coffinite, and pitchblende, and to determine their commonly interrelated habits of occurrence in representative ores.

18. Solubility of methane in brines (uranium study as part of Branch of Experimental Geochemistry and Mineralogy project) (K. A. McGee)--examine geochemical behavior of oxygen, hydrogen, selenium, sulfur, and uranium in low-temperature aqueous solutions such as are involved in the formation of sandstone-type ore deposits.

19. Laboratory, field, and computer flow study of the origin of Colorado-Plateau type uranium deposits (Colorado State University, D. K. Sunada)--examine the movement and precipitation of humic acids under variable flow conditions in porous media containing baffles and simulating sandstones with mudstone lenses.

20. Isotopic and field investigations of Morrison sedimentation patterns in the San Juan Basin (California Institute of Technology, L. T. Silver)--use isotopic and other geochemical measurements of zircons and other heavy minerals in sandstones and shales of the Morrison Formation to determine differences in sediment source areas and vertical and lateral patterns of sediment transport and alteration.

21. Clay-uranium interactions and formation of clay-uranium complexes (Pennsylvania State University, G. W. Brindley)--examine in the laboratory the chemical mechanism of fixation of uranium by clays.

22. A ^{13}C nuclear magnetic resonance (NMR) study of humic acid, its structure, and its interactions with metallic ions (Colorado State University, G. E. Maciel)--apply NMR to elucidate structure of humic acid and its chemical reaction with uranium.

23. A stable isotopic study of granites related to uranium-thorium deposits (University of Georgia, D. B. Wenner)--use oxygen isotopes as indicators of the origin of specific granites and the reasons for their uranium fertility.

24. Study of the role of microorganisms in the deposition of uranium ores (Colorado School of Mines, D. M. Updegraff)--examination of kinetics of uranium reduction by H_2S at different pH levels.

25. Study of sorption of uranium by iron-mineral species (Colorado School of Mines, D. B. Langmuir)--equilibrium sorptive characteristics of iron oxyhydroxides and uranium.

26. Study of solubility of uranium oxides in aqueous fluoride solutions (Colorado School of Mines, S. B. Romberger)--experimental study of fluoride complexing of uranium under hydrothermal-system conditions.

Uranium in sedimentary environments (J. A. Campell, coordinator):

1076 1. Stratigraphic and sedimentary environment studies, San Juan Basin (M. W. Green)--apply modern stratigraphic techniques to stratigraphic correlations within the Morrison Formation and related units in developing an understanding of uranium mineralization.

1078 2. Stratigraphic analysis of Tertiary uranium basins of Wyoming (D. A. Seeland)--develop uranium-occurrence models based on sedimentary environments and fluvial patterns; investigate possible structural and topographic control on paleostream courses which are loci of mineralization.

1348 3. Stratigraphic analysis of the Western interior Cretaceous uranium basins (H. W. Dodge, Jr.)--determine the character and environment of deposition of Cretaceous rocks which contain uranium deposits and investigate their relation to uranium favorability.

1430 4. Basin analysis as related to uranium potential of Triassic sedimentary rocks of the eastern United States (C. E. Turner-Peterson)--define sedimentary environments and their relation to uranium mineralization in fault-trough sedimentary rocks of the Appalachian Piedmont.

1431 5. Basin analysis as related to uranium potential in Permian rocks of the Colorado Plateau and midcontinent region (J. A. Campbell)--define areas of uranium potential and controls on mineralization through depositional-environment and stratigraphic studies (with emphasis on the Cutler Formation of the Colorado Plateau).

2302 6. Sedimentology of the Ambrosia Lake uranium district, San Juan Basin, N. M. (C. E. Turner-Peterson)--elucidate sedimentational influence on ore deposition through detailed surface, subsurface, and mine studies, with attention to paleocurrent indicators and possible lacustrine facies.

2290 7. Uranium geology and potential resources of the Tertiary of the Great Plains (K. A. Dickinson)--define areas favorable for uranium mineralization on the basis of stratigraphy and depositioned environment; investigate the Denver Basin, including radiometric and geochemical sampling of soils and weathering profiles.

1432 8. Basin analysis of uranium-bearing Jurassic rocks of the Colorado Plateau (Fred Peterson)--re-evaluate stratigraphy and uranium occurrence in terms of depositional-environment factors, with emphasis on the Salt Wash Member of the Morrison Formation in the Henry Mountains and Uravan districts.

1433 9. Basin analysis of uranium-bearing Triassic sedimentary rocks of the Colorado Plateau (R. D. Lupe)--re-evaluate stratigraphy and uranium occurrence in terms of depositional-environment factors, using surface and subsurface data to establish depositional packages on a regional scale across Utah, Arizona, and New Mexico.

0044 10. Uranium deposits of Wyoming (F. C. Armstrong)--prepare a report completing previous studies on the Gas Hills district.

2095 11. Uranium studies in western Arizona Tertiary basins (J. K. Otton)--define the geologic setting and, uranium mineralization in the Date Creek and similar basins, with attention to volcanic sources and lacustrine paleoenvironments.

0174 12. Middle and late Tertiary history of parts of the northern Rocky Mountains and Great Plains uranium regions (N. M. Denson)--define Tertiary history of source areas and adjacent basins, emphasizing regional synthesis of surface and subsurface data for the Powder River Basin.

0209 13. Stratigraphic and geochemical studies of uranium host strata, Powder River Basin, Wyo. (E. S. Santos)--determine physical and chemical relations of ores and host rocks, with emphasis on detailed subsurface exploration data to define facies and structure in uranium districts.

0196 14. Geologic studies of the Badwater Creek-Copper Mountain uranium area, Wyoming (R. E. Thaden)--map the area in detail geologically and define those aspects related to uranium occurrence in an area of major new discoveries of uranium associated with granite.

1438 15. Sanostee, N. M. uranium studies (A. C. Huffman, Jr.)--provide a framework for uranium studies and exploration through quadrangle geologic mapping.

1439 16. Window Rock, N. M.-Ariz., uranium studies (R. E. Thaden)--provide a framework for uranium studies and exploration through quadrangle geologic mapping.

1440 17. North Church Rock, N. M. uranium studies (R. A. Kirk)--provide a framework for uranium-occurrence modeling and exploration through geologic mapping and subsurface and mine studies, including more regional framework studies of exploration data and LANDSAT images.

1815 18. Chama Basin, N. M.-Colo. uranium studies (J. A. Ridgley)--map the area geologically and define stratigraphic relations with the sequence in the neighboring San Juan Basin; develop exploration guides.

1858 19. Crownpoint, N. M. uranium studies (J. F. Robertson)--to map the area geologically, relating uranium occurrence to stratigraphy, with emphasis on mine studies to establish detail of geologic relationships.

1436 20. Uranium potential of the Lower Cretaceous rocks of the Uinta and Piceance Creek Basins, Utah-Colo. (L. C. Craig)--define depositional environments and their relation to uranium occurrence.

1680 21. Uranium potential of Tertiary sedimentary rocks in Alaska (K. A. Dickinson)--study sedimentary environments in selected basins as potential analogs of major uranium areas elsewhere, and examine favorability in terms of Alaskan paleoclimatic and geochemical conditions.

0178 22. Uranium potential of the southern High Plains (W. I. Finch)--define habits of uranium occurrence in Triassic, Jurassic, and younger rocks as guides for exploration.

23. Study of fluvial-lacustrine environments of uranium deposits in the Texas coastal plain (Texas Bureau of Economic Geology, W. A.

Galloway)--definition of fluid flow systems in a subsiding basin, with respect to localization of uranium deposits.

24. Field study and modeling of Colorado Plateau-type uranium deposits (Colorado State University, F. G. Ethridge)--detailed sedimentologic work in Slick Rock district, Colorado, and computer simulation of uranium-deposit environment.

Uranium in Igneous and Metamorphic Environments (C. S. Bromfield, coordinator):

1349 1. Geologic studies of the Midnite mine uranium area, Washington (J. T. Nash)--define geologic setting, mineralogy, geochemistry, and genesis of the uranium deposits; establish a model of granite uranium fertility and develop exploration guides.

1857 2. Uranium potential of vein-disseminated deposits in western United States (J. T. Nash)--develop geologic guides to new deposits and document mechanisms of uranium concentration with initial emphasis on area studies of mineralogy, chemistry, and petrology of the Front Range and Pitch mine in Colorado.

1434 3. Uranium potential of the Basin-and-Range Province (C. S. Bromfield)--determine uranium-favorable environments by reconnaissance methods and selected detailed study of possible analogs of known mineralized volcanic and basin-fill environments.

1442 4. Uranium veins in eastern United States (R. I. Grauch)--determine favorable environments and genesis of uranium occurrences and develop models and exploration guides.

1441 5. Marshall Pass, Colo. uranium-thorium studies (J. C. Olson)--determine the geologic setting and controls of mineralization.

1827 6. Uranium potential of plutonic rocks of the northeast United States (E. L. Boudette)--evaluate potential for vein, disseminated, and contact-metamorphic uranium deposits, including compilations of granite geochemical data and development of a model of petrology and tectonic setting of uranium-favorable granites.

2152 7. Uranium investigations in metamorphic rocks of the Great Lakes region (David Frishman)--define uranium-rich Precambrian rocks or favorable environments analogous to those of foreign unconformity-vein, quartz-pebble conglomerate, and granite uranium deposits.

1687 8. Western Alaska uranium studies (T. P. Miller)--investigate potential for uranium-thorium deposits in plutonic rocks of the Seward Range and their eastward extension.

1673 9. Uranium potential in Precambrian sedimentary and metasedimentary rocks (F. A. Hills)--define, by isotopic and other methods, Precambrian basin environments suitable for quartz-pebble conglomerate and quartzite uranium deposits, and develop models of such habitats.

2403 10. Favorability studies, "world-class" non-sandstone deposits (J. T. Nash)--NURE-program investigations of areas having potential for giant deposits like those in nonsandstone terrains of Canada and Australia.

11. Geologic and mineralogic interpretation of gamma-ray reconnaissance data for the Reading Prong, eastern Pennsylvania (Pennsylvania Topographic and Geological Survey)--establish the geologic and geochemical nature and source of anomalous radioactivity measured in local areas by aerial surveys.

12. Study of granites related to uranium deposits in northeast Washington (Colorado School of Mines, E. C. Simmons)--geochemistry of strontium and other granite evolutionary indicators, with emphasis on granite as a source of uranium.

Geophysical Techniques in Uranium and Thorium Exploration (D. L. Campbell, coordinator):

[Numbers in margin refer to project number, Branch of Petrophysics and Remote Sensing]

1706 1. Remote sensing in uranium exploration (G. L. Raines)--refine remote-sensing techniques for recognition of geologic features (structure, facies, and alteration) associated with uranium deposits, with emphasis on the development and application of ways to improve computer enhancement of satellite- and aircraft-image data, on the testing of data from new imaging systems, and on the development of new spectral-reflectance data and interpretative techniques.

1708 2. Gamma-ray spectrometry in uranium exploration (J. S. Duval)--refine existing aerial-survey tools and techniques and develop interpretive methods. Two main thrusts are the testing of an unconventional aerial instrument which uses a plastic scintillator instead of a fragile sodium-iodide crystal, and development and application of a method for improving data interpretation by converting profile information into color-composite images.

1709 3. Mineral exploration by gamma-ray spectrometry in crystalline rocks (J. A. Pitkin)--test and apply a truckborne spectrometer in mountainous areas unsuited for aerial surveys.

1712 4. Geophysical studies relating to uranium deposits in crystalline terranes (D. L. Campbell)--test and refine nonradiometric geophysical methods for exploration and study of uranium deposits in igneous and metamorphic areas.

1710 5. Uranium geophysics in frontier areas (J. W. Cady)--test the use of geophysical data on regional and local scale to establish environments favorable for uranium by analogy with geophysical settings of known uranium areas.

1711 6. Borehole geophysical research in uranium exploration (J. H.

Scott)--develop borehole geophysical-data acquisition and computer-interpretation techniques for detecting uranium deposits and defining geologic loci of mineralization.

7. Surface electromagnetics in uranium exploration (Branch of Electromagnetism and Geomagnetism) (B. D. Smith)--apply and evaluate induced polarization and other nonradiometric methods for detection of uranium deposits or favorable geologic environments.

2059 8. Uranium petrophysics (G. R. Olhoeft)--collect basic data on physical and electrical properties of ore and surrounding rocks to aid in instrument development and application of field techniques.

9. Uranium disequilibrium studies (Branch of Isotope Geology project) (F. E. Senftle)--develop a downhole probe for direct high-sensitivity assays of uranium and thorium and measurement of disequilibrium between those elements and their daughter products in radioactive decay.

2644 10. Southern Utah remote sensing (M. H. Podwysocki)--use of computer-enhanced aircraft and landsat images to define altered ground and structural setting of uranium deposits, Marysvale district.

1647 11. San Juan Basin remote sensing (D. H. Knapper)--definition of lineaments and spectral-reflectance patterns in Landsat images.

12. Magnetic map of San Juan Basin (Branch of Regional Geophysics project) (L. E. Cordell)--interpretation of aeromagnetic data and modeling studies.

13. Evaluation of a high-efficiency fast-neutron flux monitor with application to uranium exploration (Colorado School of Mines, F. E. Cecil)--test an experimental method of high-sensitivity measurements of low-energy gamma rays useful in direct scintillation assay of uranium.

Uranium Resource Assessment (W. I. Finch, coordinator):

2038 1. Uranium resource assessment (W. I. Finch)--develop methods of estimating undiscovered resources, based on models of uranium deposit occurrence and computerized techniques for comparing geologic factors around uranium deposits with geologic factors in areas where resources are being assessed.

2149 2. Uranium resource analysis (R. B. McCammon)--apply statistical tchniques in an effort to establish in control areas relationships between ore-deposit occurrence and arrays of geologic features, and quantify these relationships and deposit size and grade data as a relatively objective, data-based framework for resource assessment in areas resembling the control areas.

Thorium Investigations and Resource Assessment (T. J. Armbrustmacher, coordinator):

01942 1. Thorium investigations in igneous rocks (M. H. Staatz)--study in detail geologic setting and size, shape, mineralogy, and geochemistry of significant thorium deposits.

0189 2. Cochetopa, Colo. uranium-thorium deposits (J. C. Olson)--perform detailed geologic mapping and other studies to establish setting and resource potential of the deposits.

1347 3. Thorium-resource appraisal of the Wet Mountains district, Colorado (T. J. Armbrustmacher)--study known thorium-rich veins and investigate the processes of thorium concentration in the light of petrologic and geochemical information on alkalic magmatic rocks.

4. Resource evaluation of thorium and associated heavy-mineral-bearing sands of the Coastal Plain of Georgia (Geologic and Water Resources Division, Georgia)--conduct mineralogic studies and evaluate resource potential of heavy-mineral concentrations in fossil beach sands.

APPENDIX 3

URANIUM AND THORIUM RESOURCES PROGRAM BIBLIOGRAPHY 1977-78

[Key to code in margin: UGM--uranium geochemistry and mineralogy; US--uranium sedimentary environments; UIM--igneous and metamorphic environments; GP--geophysical techniques for exploration and assessment; TH--thorium investigations]

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GP Brooks, R. A., and Finch, W. I., 1977, Carborne radiometric survey of the Nome area, Seward Peninsula, Alaska: U.S. Geological Survey Open-File Report 77-472, 22 p., 1 fig.

URA Bromfield, C. S., 1978, Map showing appraisal of mineral resource potential of RARE II proposed roadless areas in National Forests, Utah: U.S. Geological Survey Open-File Report 78-914, 1 pl., Scale 1:500,000.

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