Letters

Naloxone Antagonism as Evidence for Narcotic Mechanisms

In her excellent Research News article, "Analgesia: How the body inhibits pain perception" (4 Feb., p. 471), Jean L. Marx reports on recent data which have been interpreted as indicating that acupuncture analgesia is mediated by the same neural mechanisms as those participating in the analgesia resulting from the administration of narcotics. The inference that acupuncture and narcotics share common neural processes is based primarily on the observation that the analgesia produced by both procedures is antagonized by naloxone, a drug commonly represented to be a specific antagonist of narcotic effects.

In view of the considerable public interest that acupuncture analgesia has generated, statements about its possible mechanisms of action should be based on more definitive lines of evidence. As Marx points out, recent work in our own and other laboratories suggests the existence of at least two physiologically distinct mechanisms capable of modulating responses to painful stimuli. Such demonstrations highlight the need for rigorous research strategies to distinguish narcotic from nonnarcotic mechanisms of analgesia.

Several considerations suggest that conclusions are premature regarding the commonality of neural mechanisms mediating acupuncture and narcotic analgesia. First, there is a growing body of evidence which makes suspect the contention that naloxone antagonizes only the effects of narcotics by preventing the binding of narcotic drugs to their specific receptors. Naloxone has been shown to antagonize the analgesic consequences of a variety of nonnarcotic manipulations. In addition to acupuncture, these manipulations have included the administration of nitrous oxide, lanthanum, cannabinoid analogs, and acetylcholine, as well as electrical stimulation of the brain (*1*). Aside from studies using analgesic measures, naloxone has been shown to interact with a variety of other effects. For example, naloxone has been reported to antagonize fatigue in the guinea pig ileum (which is commonly used to study narcotic action), in addition to antagonizing other responses produced by cholinergic agents, glutamate, and *d*-amphetamine (*2*). Alternatively, since excitatory and facilitatory effects of the drug even at modest doses cannot be excluded (*3*), it is also possible that certain cases of naloxone antagonism could result from activation of some opposing system rather than from pharmacological competition for narcotic receptor sites. We wish to point out, however, that we do not rule out the possibility that some or all of the above effects are mediated by interactions with endogenous opiate-like substances or their receptors.

We wish to emphasize, also, that in certain situations naloxone antagonism may be a necessary condition to infer activation of a narcotic system, since to our knowledge naloxone has not failed to antagonize narcotic analgesia. Thus experiments in which naloxone does not antagonize the effects of an analgesic manipulation at least provide evidence against involvement of a narcotic system.

To summarize, it has long been recognized in careful pharmacological studies that naloxone antagonism is necessary but not sufficient to infer a narcotic mechanism of action. While the need for additional lines of evidence has not been universally ignored (*4*), we feel this approach should be given more explicit attention in current behavioral and physiological research.

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Myelin Basic Protein: Clinical Trials

We wish to correct an impression that may be given in the Research News article of 11 March (p. 769) about multiple sclerosis by Thomas H. Maugh. Contrary to a statement in the article, a clinical trial of myelin basic protein in multiple sclerosis patients has not begun at the University of Toronto.

A trial has been proposed to clinicians in the neurology program at the university; however, the protocol is still in the developmental stage, so that a date for commencing a study cannot be forecast.

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Uranium Resources

The long-run marginal cost of uranium oxide (U_3O_8) is a key factor in major policy questions regarding the development of nuclear energy. Current debates about the economic desirability of breeder reactors, spent fuel reprocessing, and plutonium recycling all hinge critically on the question of how much uranium can be produced at what cost. Advocates of the new technologies argue that rapidly growing demand and limited resource supplies necessitate prompt action to permit continued use of nuclear fission energy (*1*). Critics argue that demand has been overstated and supply understated and, consequently, that there is no need for an early decision to undertake recycling or reprocessing or to proceed more rapidly with breeder development (*2*).

There *is* a great deal of uncertainty about the supply of uranium. Very large amounts of high-cost uranium (forward costs of more than $125 per pound of U_3O_8) evidently exist in the Tennessee shales and Conway Granites. The relevant policy question is, however, whether substantially more low-cost ores (forward costs of less than $50 per pound) remain unexploited (*3*). M. A. Lieberman, in his article "United States uranium resources—an analysis of historical data" (30 Apr. 1976, p. 431), utilizes the so-called "Hubbert" hypothesis to estimate the ultimate recoverable uranium resources available from the western sandstone deposits, where most domestic production has occurred in the past. Lieberman characterizes this approach as "prudent" and the resulting estimates as "objective" and concludes that the

Energy Research and Development Administration (ERDA) has overstated the available resources by a factor of 3. Lieberman's critique of ERDA's estimating method is that it is "entirely speculative" and "not based on any objective procedures." In Lieberman's terminology, "objective" appears to mean "based on historical discovery yields."

The main reason why supply estimates are made is that future resource availability is important for present decisions. It is impossible to remove all uncertainty. The problem is how to go about making good decisions when uncertainty is unavoidable. A standard practice is to use the expected value or mean of the random variable if it is necessary to characterize the full range of possible outcomes with a single number. A reasonable criterion for an "objective" estimating procedure is the requirement that it give an unbiased estimate of the expected value of the random variable. Accordingly, we are concerned with the extent to which both Lieberman's and ERDA's estimates of uranium supply are biased. We believe the preponderance of the evidence indicates that these estimates substantially understate the expected value of the actual resource availability.

Because the supply of any mineral depends upon the outcome of future exploration, supply is intrinsically uncertain. One way of estimating ultimate resources is to use the "Zapp" hypothesis, which extrapolates forward known discoveries by the ratio of unexplored areas or depth horizons to the known areas. This method results in upwardly biased estimates because it assumes both that there is no geological selectivity in the habitat of the resource and also that the explorer uses no a priori indicators as a basis for preferential drilling. As long as explorers look in the most likely places first, there should be a natural decline in exploration productivity for any given level of exploration technology. But minerals exploration has experienced, and surely will continue to experience, technical advances in sensing devices, geologic models, and drilling rig productivity (*4*) that have dramatically increased exploration productivity. And technical advances in mine development methods and ore milling processes can also help expand the supplies available from limited resources. Evidence presented by Potter and Christy (*5*) indicates that demands for most minerals have grown exponentially during the first 50 years of their exploitation, while deflated prices have either declined or remained relatively constant. Technical advance surely must play some role in this phenomenon, and the possibility of similar advances in the future implies that supply estimates based upon extrapolations from existing exploration, mining, and processing technologies are biased downward.

At any point in time, the amount of known resources producible at specific prices is largely determined by the amount of exploration that has taken place to date. The amount of exploration undertaken by the private sector and the exploratory strategy adopted are both in turn determined by the anticipated selling price of the sought-for mineral. Natural gas explorers will, for example, drill deeper wells farther offshore the higher is the allowed price for natural gas (*6*). It follows directly that estimates of potential resources available at prices above expected future price levels can be seriously understated if they are based on the amount of known resources. We contend that the Lieberman and ERDA resource estimates fail to reflect this relationship between selling price and exploratory strategy and, therefore, significantly understate actual resource availability.

A potentially serious negative bias for all potential resource categories arises from the specific nature of uranium exploration and discoveries in the United States. Most of the uranium exploration and discovered reserves in the United States have been in sandstone-type deposits in the mountain states of the West. The majority of reserves in the rest of the world are found in other types of deposits. Extensive exploration for nonsandstone deposits in the whole of the United States, including Alaska, may produce an entirely different picture of U.S. supply.

The important question is why there has been so little exploration outside the sandstone deposits in the major producing states. If explorers have anticipated prices equivalent to cutoff costs of at least \$30 per pound of U_3O_8 and carried out all the exploration that they deem profitable, then the ERDA estimates are an unbiased estimate of potential resources in all types of deposits and in all areas. Alternatively, the early discovery of substantial low-cost sandstone deposits in western states may have acted to lower anticipated selling prices and discouraged additional exploration in other areas. Indeed, this seems to be the case, as actual market prices for uranium fell almost continuously until 1973, reaching levels below \$10 per pound in current dollars. There were peak periods of private exploration activity in 1956 and 1969 which resulted in substantial increases in low-cost reserves in western sandstone deposits. Since 1973, prices and exploratory activity have increased, although the \$40 per pound spot prices now quoted may exaggerate long-term price expectations relevant for exploratory strategy decisions. Even at \$40 per pound, it is doubtful that explorers have carried out all the exploration that they deem profitable. It is true that the finding rate per foot drilled (a measure of exploration productivity) has generally declined over time, but this drilling has been almost completely restricted to sandstone-type deposits. We draw the conclusion that, while the ERDA estimates may be unbiased or even high for shallow sandstone deposits in the western states, they surely underestimate the amount of potential resources to be found elsewhere in the United States. Less than 30 percent of the potential resources reported by ERDA are from regions other than the most productive areas in the western states.

A startling anomaly in the ERDA estimates of U.S. uranium supply is that there is virtually no uranium producible at costs between \$30 and \$125 per pound from U_3O_8. One obvious explanation for the lack of known or potential resources for costs above \$30 per pound is that there has been little past exploration aimed at finding such deposits. Indeed, uranium explorers may have been persuaded by the uranium price decline over the past three decades that only low-cost uranium deposits less than \$10 per pound were worth looking for. This lack of reserves or potential resources producible for \$30 to \$125 per pound lends further support to the notion that estimated supply at moderate costs of \$15 to \$30 per pound are also seriously biased downward by the lack of exploration directed at low-grade resources.

Lieberman's "prudent" estimate of the ultimate recoverable resources from the western sandstones is less than one-third of ERDA's estimate of total supply. Whether it would be prudent to base policy decisions regarding plutonium recycling and breeder reactors on resource estimates that are arguably biased downward is an open question. A biased estimate could provide a prudent basis for policy decisions if there were an asymmetry associated with the costs of forecasting errors in the positive and negative directions. If the costs associated with upwardly biased estimates exceed those associated with downwardly biased estimates, then a prudent approach might warrant the use of estimates that are biased downward. If the reverse were true, prudence would argue for the use of upwardly biased estimates. Without estimating the comparative costs of being wrong, there is no basis for claiming that downwardly biased estimates are prudent.

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4. Technical change that increases drilling productivity, such as the rotary drill, may take the form of technological breakthroughs, but recent evidence suggests that it is also the result of technically competent people solving day-to-day problems in drilling rig management. See F. M. Fisher, in *The Energy Question: An International Failure of Policy*, vol. 2, *North America* (Univ. of Toronto Press, Toronto, 1974).
5. N. Potter and F. T. Christy, Jr., *Trends in Natural Resource Commodities*, P. Manning, Ed. (Resources for the Future, Washington, D.C., 1962).
6. Differences in oil and gas exploration in the North Sea and the Gulf of Mexico provide an interesting illustration of the effects of price on exploratory strategy. Exploration generally begins with geophysical analysis designed to identify geological structures that may contain deposits. Geophysical data are obtained by seismic techniques that use sound waves to develop a picture of the contours and thicknesses of underground rock layers. In the North Sea, miles of seismic data per square mile are only about one-fiftieth of that in the Gulf largely due to wider grid spacing. This difference is in turn partially attributable to the higher production costs in the North Sea. With higher costs, only large deposits may be profitably exploited. With a wider grid, a large number of small deposits may be missed, but most large deposits will be found. If prices rise or costs decline, smaller deposits will become profitable and narrower grid spacing would be appropriate.

Lieberman's article contributes to the growing volume of analyses of uranium resources (*1, 2*). His estimates require comment, as they are well outside the range of other current estimates (*2*). Although there are a number of problems with the uranium discovery figures provided by ERDA (*3*) which make resource estimation difficult, these have been commented on elsewhere (*4*), and attention here will be focused on the \$8 per pound of U_3O_8 discovery series. This series plays a key role in Lieberman's conclusions, and an apparent misunderstanding of its nature leads Lieberman to underestimate uranium resources.

Confusion concerning this series is widespread. This series is often treated as if it had been adjusted to a constant dollar basis by ERDA. This is not the case, nor does ERDA purport it to be. The series is a current dollar series, and projections derived from it are in current dollars, not constant dollars. Although ERDA has in recent years made adjustments to the reserves estimates to account for erosion by inflation of material no longer producible at fixed forward costs, these adjustments have only dealt with the current year's estimate of the total, and estimates made in previous years have not been affected.

Lieberman's resource projection is for a series in which additions are being restricted by ever tightening cost criteria. While the individual year effect of inflation on the total has, as Lieberman points out, been significant only during the last few years, the cumulative effect of inflation over the time period under analysis has been significant indeed. An ore body which, if discovered in 1948, would have had forward costs of \$8 (in 1948 dollars) per pound would have had forward costs of about \$22.50 (in 1973 dollars) if discovered in 1973 (*5*). It would not have been included in additions to \$8 (current) dollar reserves in the 1973 statistics. In fact, it probably would not have been added to reserves at all, even in the up-to-\$30-forward-reserve category, as such higher cost reserves generally have not been evaluated unless they are associated with lower cost material. Much of the historical decline in discoveries per exploratory foot shown in Lieberman's table 1 can be attributed to the fact that the \$8 current reserve category is one for which it has been more and more difficult for new discoveries to qualify due to inflation. A decline from a discovery rate of as much as 15 pounds per foot in the pre-1967 period to 5 pounds per foot for a constant drilling depth could possibly be accounted for on this basis alone.

Notwithstanding the additional problems with the data discussed below, if one bears firmly in mind that Lieberman is projecting a current dollar series with an implicit inflation rate of perhaps 4 to 5 percent per year, then his projection that only 87,000 additional tons in this class will be found is not unreasonable, since, depending on when one assumes the discoveries to be made, these discoveries are made under an upper cost limit of \$3 to \$5 in 1973 constant dollars (1973 is the last year used in Lieberman's analysis).

There are other complications in using discoveries per exploratory foot as a measure. Exploratory drilling is but a part of the exploratory effort, and it cannot be assumed that the role of drilling relative to the other activities undertaken to find uranium has been constant during the period of analysis. For example, in the early years a great deal of uranium was discovered by the use of Geiger counters and other essentially surface techniques unrelated to exploratory drilling. Inclusion of these discoveries in a "discoveries per exploratory foot" measure biases the slope in a downward manner. If it were possible to exclude these discoveries, the slope of the line might be significantly different. It is interesting, and, possibly significant, that for the last three of Lieberman's 11 data points (in his figure 2) there is no longer any decline, in spite of the strong downward slope of the overall function.

A related problem is that a substantial portion of reserves are added by development drilling or as a result of mining but not on a credited back-to-year-of-discovery basis. It is quite conceivable that in a given area in a given year there might be no discoveries of new ore bodies and no additions to reserves from exploratory effort and still large additions to reserves from development drilling in and mining of known ore bodies, thus giving a completely erroneous measurement. The use of total footage, as opposed to exploratory footage, is probably an equally valid measure. Yet neither measure is entirely satisfactory.

An important factor that has influenced the discovery rate measured on a drilling footage basis is the changing depth of hole. The average depth of exploratory hole has more than tripled since 1964. Consequently, the discovery rate per foot to find an ore body in 1974 equal in size to one found in 1964 has declined threefold. However, because exploratory costs are not included in forward costs, decreasing success as measured by discoveries per exploratory foot tells us only that the depth of drilling is increasing and not that forward costs are increasing, at least anywhere proportionally, or that there is less uranium per unit of volume as we go deeper. Holes drilled may be a more relevant measure than footage drilled. Preliminary analysis on the basis of discoveries per hole indicates more favorable trends than discoveries per foot or per exploratory foot.

Lieberman's projections of material to be found in the higher cost categories are suspect on several grounds. First, since they are based on the validity of the projection of \$8 reserves, it is highly questionable for the reasons outlined above whether any meaningful analysis is possible. Second, Lieberman appears to implicitly assume the material in these classes are the results of independent effort. In using a simple ratio based on past experience of these classes relative to the \$8 class, he does not take into account the fact that exploration has primarily been directed at finding the lowest cost materials, and that approximately

90 percent of the $30 per pound forward cost reserves are located in deposits also containing low-cost reserves. Almost all of the material in higher cost categories is associated with lower cost deposits and is in no sense an independent sample of what exists in nature. It is erroneous to assume that deposits do not exist that are not associated with low-cost material. In fact, a number of such deposits have been encountered in this country but, without incentive, these occurrences frequently have not been recorded or their extent confirmed. Stemming from and aggravating this situation is the fact that much of what explorationists have been able to perceive of the existence of lower grade (U_3O_8 in the range of hundredths to tenths of a percent) material has been limited by inadequate logging devices. Essentially all that Lieberman has been projecting in the higher cost categories is the material that will be found associated with his projection of $8 per pound material, not independent deposits.

Lieberman's use of the declining discoveries–cumulative footage relationship and the bell-shaped production curve deserves additional comment. Lieberman justifies the application of these techniques to uranium estimation on the basis that there is a similarity between uranium and oil deposits, namely, the size distribution of both types of deposits shows that only a few deposits contain the greatest reserves. Even given the perhaps questionable assumption that such techniques are applicable to oil estimation, Lieberman fails to address the question of whether the history of uranium exploration is sufficiently mature to permit the meaningful application of such techniques. It is here that the similarity between experiences with uranium and oil ceases. George G. Hardin, vice president for exploration of Kerr-McGee Corporation, one of the nation's major uranium producers, said in 1973: "So far, the search for uranium has been based largely on the surface shows of radioactivity. Uranium exploration is now in the same stage as oil exploration was in the days when oil seeps were the primary basis for drilling wildcats . . ." (*6*). The facts that average uranium drilling depths are now around 600 feet and that there are not known reasons why uranium should not exist at any depth in favorable sandstone formations tend to confirm Hardin's view.

Several other aspects of an admittedly complex situation are largely ignored by Lieberman (*7*). One is the effect that new discovery technologies may have. The Electric Power Research Institute, in conjunction with ERDA and others, is exploring the use of helium isotope ratios as indicators of the location of deeper uranium deposits (*8*). This could reduce the need for exploratory drilling and make more uranium available at lower costs than otherwise. Moreover, Lieberman's analysis is largely confined to known producing areas and to sandstone-type deposits. There is substantial promise in other areas and other types of deposits similar to those that exist in the rest of the world. Also, present-type light water reactors could use uranium at much higher costs, say up to $100 per pound in 1975 dollars, without crippling economic penalties. A large amount of uranium probably exists in higher cost categories not considered by Lieberman as we have tried to show elsewhere (*9*).

The views we express on uranium resources should not be interpreted to mean that there may not be uranium supply, as opposed to uranium resource, problems, or other unresolved issues concerning nuclear power. Some studies, including one sponsored by the Edison Electric Institute (*10*), indicate that there may be problems in finding, mining, and milling uranium resources fast enough to meet assumed schedules of nuclear plant construction.

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Gaskins and Haring, Searl and Platt, and others (*1*) have criticized the discovery rate procedure of estimating ultimate recoverable mineral resources (Q_∞) and its application to uranium resource estimation. Before replying, I should note the following. The discovery rate estimate in my article applies to the western sandstone districts of the United States only. The ERDA estimate of Q_∞ in the $30 per pound category is over three times larger than the discovery rate estimate. The authors of both of the above letters assert that the ERDA estimate is low. Criticism of the procedure itself applies equally to petroleum and natural gas estimation, where discovery rate estimates agree (*2*) with those derived from other, currently accepted, procedures.

Inflation and productivity increases. Searl and Platt ignore uranium productivity increases and conclude that much of the observed decline in discovery rate over the years is due to inflation. Gaskins and Haring mention past increases in productivity but conclude that the discovery rate procedure extrapolates from existing technology and ignores future productivity increases. Neither conclusion is correct.

An objective measure of the combined effect of inflation and productivity increases on the discovery rate is the variation of the grade of the cumulative uranium discoveries by year (*3*, *4*). The striking feature of these data is the slight, long-term, declining trend in average grade. The decline "bottoms out" during 1970–73 and the grade rises substantially for the last drilling interval in 1974, a year of severe inflationary pressure. It is clear that any supposed reduction in finding rates over the last 25 years due to the effect of inflation is a chimera. Such a reduction would be due to the increasing grade at which discoveries are reported to meet a constant criterion of $8 per pound forward cost. Up through 1973, increases in productivity have more than matched the inflationary pressures the uranium industry has experienced. Since past technical advance is included in the historical data, the discovery rate extrapolation assumes a continuation of that advance into the future. The discovery rate estimate is not biased downward by the assumption of a static technology.

Early excess surface exploration. It is suggested that discoveries by prospectors with Geiger counters have led to artificially high discovery rates during the early drilling intervals. As an upper bound on the supposed effect of surface exploration in distorting the discovery rate data, one may consider that the first three drilling intervals, embracing the drilling years 1948 through 1957, should be discarded in the analysis. A least square fit to the remaining seven drilling intervals yields a value of Q_∞ which is roughly 6 percent higher than the value obtained by fitting to all ten intervals (*4*). Therefore, excess surface exploration is not a significant factor in distorting the discovery rate estimate of Q_∞.

Drilling and ore depth. Searl and Platt suggest that the proper measure of exploration effort is not the exploratory footage drilled but rather the number of exploratory wells drilled. They argue that drilling depths have markedly increased, and that much of the decline in discovery rate can be attributed to the increase in average hole depth. This conclusion is in error.

While it is true that the average exploratory hole depth has increased by a factor of 3 since 1964, practically the entire increase occurred during the period from 1964 through 1966, when drilling was at its nadir, with less than 3 million feet drilled during these 3 years (*5*). For the 9-year period from 1967 to 1976, during which the discovery rate declined by almost a factor of 3, the average hole depth was relatively constant, increasing by only about 20 percent.

The uranium industry has traditionally considered the footage drilled to be the proper measure of its exploratory effort (*6–8*). However, it is of interest to calculate Q_∞ based on an extrapolation of the discovery rate per well drilled, as if that were the proper measure. An objective estimate of the supposed effect of increasing drilling depth is then obtained. The cumulative number of wells drilled from 1961 to 1974 were therefore divided into eight intervals of between 25,000 and 50,000 wells each. The discovery rate was calculated and a declining exponential curve was fit to the data points. The value of Q_∞ so obtained (*4*) is only 15 percent larger than the value obtained from the discovery rate per foot drilled, over the same time interval.

Searl and Platt suggest that the uranium per unit volume in the sandstone formations is roughly independent of depth. If one assumes this is true, it is erroneous to conclude that large quantities of deep, economically recoverable uranium remain to be discovered, awaiting only an increase in drilling depth. For a given forward cost, a deep deposit is far less likely to be producible than an equivalent surface deposit. It is highly relevant to note that the average depth of the entire \$30 per pound ERDA "probable" potential resource (1.06 million tons of U_3O_8—almost entirely in sandstone) is approximately 800 feet (*9*). Since the average drilling depth is currently around 550 feet (*5*), it seems improbable that any large increase in drilling depth will occur during the next few decades.

Higher cost category resources. The authors of both letters suggest that extrapolation to higher cost category resources by means of a tonnage/forward-cost ratio yields an underestimate, being based on the distribution of known resources. The relation between average ore grade and forward cost in current dollars is calculated yearly by ERDA (*2*) and is not in dispute. The central question is the establishment of a tonnage-grade relation for the western sandstone deposits. This relation is primarily a physical property of the sandstone deposits, determined by sampling of numerous formations which have been thoroughly explored and mapped. The gradational characteristics of uranium occurrence in these formations is reasonably well known. At best, the undiscovered sandstone uranium resource will expand by a factor of between 2 and 3 as the production grade decreases from its present value down to 0.05 percent. There is no dispute between ERDA and myself regarding this fact (*4*), and the central issue is therefore the question of future discoveries of sandstone ore whose gradational characteristics are reasonably well known.

Contrary to Searl and Platt's assertion, I never assumed that higher cost category material was the result of independent exploration effort, nor is such an assumption necessary. I was aware that 80 percent to 90 percent of the \$30 per pound reserves are associated with reserves in the \$8 per pound and \$10 per pound categories. My belief is that enough ground has been sampled for this distribution to be characteristic of the sandstone deposits as a whole. What objective evidence is there for the contrary, beyond a few anecdotal examples of low-grade deposits which have not been recorded?

Maturity of the uranium exploration industry. Hardin's quoted comparison of pre-1973 uranium exploration with oil exploration in the days of oil seeps deserves comment. One objective measure of maturity is the decline in discovery rate itself. By 1973, the rate had declined by almost a factor of 5 for uranium and by roughly a factor of 6 for petroleum (*10*). Another measure is the drilling density in favorable ground. By 1973, approximately one exploratory well per square mile had been drilled in the western sandstone uranium districts (*5*), while roughly one exploratory well had been drilled in every 5 square miles of prospective petroleum-producing area (*10, 11*). Exploration for uranium in sandstones is at a mature stage of development, not comparable to petroleum exploration in the days of oil seeps.

Critique of ERDA estimates. While the ERDA estimate is over 300 percent higher than the discovery rate estimate, the issues raised by Gaskins and Haring and Searl and Platt do not increase the discovery rate estimate by more than 15 percent. In order to reconcile the estimates, factors which bias the ERDA estimate upward should be examined. Currently, this estimate is based on the subjective opinions of geologists, unqualified by even a subjective measure of variance or probability of error.

A consideration of the methods used in the well-established field of petroleum resource estimation sheds considerable light on the present uranium situation. The geological analogy method and the two-dimensional tabular presentation of undiscovered resource estimates, now used by ERDA, were introduced in the 1960's by the U.S. Geological Survey (USGS) for the purpose of petroleum estimation (*10*). This introduction led to 10 years of the highest petroleum resource estimates on record. In 1972 the USGS estimate for Q_∞ was a factor of 2½ times Hubbert's estimate, and was inconsistent with the estimates obtained by all other procedures. Consequently, in 1975, the USGS abandoned the geological analogy procedure and the presentation of undiscovered resource estimates in two-dimensional tabular form, and turned to probabilistic methods which, while based on geological analogy, were qualified by estimates of variance in the results (*2*).

As part of the National Uranium Resource Evaluation program, the Atomic Energy Commission (AEC) in 1974 asked 36 highly qualified geologists for their estimate of undiscovered uranium occurring in the San Juan Basin in New Mexico, the most important uranium-producing area in the United States. The AEC estimate at that time was 740,000 tons. The median of the 36 estimates was

150,000 tons. Six estimates were above 1 million tons and 12 were below 100,000 tons (*11*). The extremely large variance of these data suggests that a resource estimate based on the subjective opinions of geologists must be treated with great caution.

Recently, the Committee on Mineral Resources and the Environment (COMRATE) of the National Academy of Sciences was charged with examining estimates of uranium resources. A conference was convened in Albuquerque, New Mexico, on 12–13 December 1974. Participants in the conference agreed unanimously that present understanding of uranium deposits is insufficient to serve as a basis for estimating resources of uranium (*7*, p. 20).

In the Shirley River Basin, Wyoming, where Getty Oil has operated since 1959, the AEC estimates far exceed Getty's own estimates. In the Powder River Basin, Wyoming, where the AEC estimated a substantial potential resource, an extensive exploration effort which began in 1967 has not been successful (*6*).

ERDA lacks information obtained from exploration of areas subsequently abandoned, including barren drill hole data. Thus substantial undiscovered resources are estimated for areas which have, unknown to ERDA, been explored. A recommendation of COMRATE is that the uranium industry "be encouraged" to furnish such information to ERDA (*7*, p. 7).

Nonsandstone uranium. Gaskins and Haring assert that ERDA has surely underestimated the nonsandstone potential resources. ERDA estimates are given for some areas which have been identified as favorable, and are based on geological analogy. For reasons mentioned above it is quite arguable that these are overestimates. Other areas are identified as favorable by ERDA, but with insufficient basis for estimation of potential resources. Gaskins and Haring apparently believe that there is a large potential uranium resource in these areas, as well as in areas not identified as favorable. Their reasoning seems to be based on the simplest sort of geological analogy. It is true that the majority of reserves in the rest of the world are found in nonsandstone deposits. But it does not follow that these other deposits will be found in the United States. In fact, the existence in the United States of significant, uranium-bearing quartz pebble conglomerates, calcrete deposits, Bancroft-like pegmatites, and black shales is extremely unlikely in view of the geology of the country (*7*, p. 21; *12*). One has only to look at the worldwide distribution of oil or coal to understand that nature is capricious.

If one assumes that a substantial resource exists in nonsandstone deposits, there is a serious question of timely discovery. Whatever one's belief regarding the maturity of the domestic exploration industry, it is certain that the foreign industry is even less mature. By far the majority of all known foreign deposits have been discovered by surface exploration techniques. Surface exploration has long since been completed in this country. Substantial numbers of museum rocks, surface and underground mine sites, and petroleum well sites and drill holes have been surveyed for radioactivity. Yet, few viable, nonsandstone deposits have been found. If these uranium deposits exist, they are lacking surface shows and must be located by sophisticated exploration techniques, including an extensive drilling program. Such a program does not now exist.

The very high uranium resource estimates of Searl have been rejected by COMRATE (*7*, p. 20). The committee could not agree regarding the ERDA estimates, with views ranging from pessimistic to optimistic (*7*, p. 18). "It may be a matter of prudence to inquire more deeply into the validity of such estimates before accepting them as a continuing basis for the formulation of national energy policies" (*10*, p. 180).

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