Accuracy of Ore-Reserve Estimates for Uranium-Vanadium Deposits on the Colorado Plateau

GEOLOGICAL SURVEY BULLETIN 1030-D

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By A. L. BUSH *and* H. K. STAGER

CONTRIBUTIONS TO THE GEOLOGY OF URANIUM

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By A. L. BUSH and H. K. STAGER

ABSTRACT

The U. S. Geological Survey has made estimates of the reserves of uranium and vanadium in the carnotite deposits explored by Geological Survey drilling on the Colorado Plateau. This report presents an appraisal of the accuracy of the reserve estimates for carnotite deposits in the Uravan mineral belt, the causes of inaccuracy, and the significance of the estimates in terms of the total known reserves of the region.

The appraisal was confined to carnotite deposits that contain ore reserves of 1,000 short tons or more. These reserves are classed as indicated and inferred reserves. Reestimates of the amount of material in the ground at the time of the original estimate were made for more than 30 deposits. This was done where information on size and grade, additional to that used at the time of the original estimate, was available. The reestimated reserves (revised reserves) include production since the original reserve estimates, plus the estimate of reserves remaining in the ground, and, therefore, can be compared with the original estimates, to furnish a measure of the accuracy of the original estimates.

The reappraisal indicates that for individual deposits the original reserve estimates range from large overestimates to very large underestimates (for both tonnage and grade). However, the original reserve estimate for the total reserves of all the carnotite deposits studied in the Uravan mineral belt is a very small underestimate. For the carnotite deposits studied in the mineral belt, the revised tonnage of ore reserves is about 15 percent greater than originally estimated. In terms of grade, the original and revised estimates are the same for U_3O_8 and differ by less than 2 pounds per ton for V_2O_5. Primarily as a function of the increased tonnage of reserves, the amount of contained U_3O_8 is about 15 percent greater, and the amount of contained V_2O_5 is about 20 percent greater than originally estimated.

All of the individual deposits contained more than half the amount of ore originally estimated. A little more than 25 percent of the deposits contain over twice as much ore as originally estimated. The errors in estimation for individual deposits are mutually compensating; as more deposits are grouped into a single estimate, the amount of error decreases both in tonnage and grade.

The general source of error in the original estimates is the restricted number of points of observation (mostly drill holes) on which the estimates are based. This is complicated by the deviation of the ore deposits from an idealized uniformly tapering layer both in plan and in section, and by the erratic distribution of metal values within the deposit. No mathematical correction can be applied to the reserve estimate to compensate for this sampling error.

As the deposits studied in the mineral belt represent a fair sample of all the uranium-vanadium deposits that the Geological Survey is finding in the Morrison formation, the realization ratios (the "accuracy of prediction" figures) given above can be applied with reasonable confidence to the total of the estimates of known reserves for all of the deposits found by the Geological Survey. This total estimate is one of the major objectives in the exploration work. As the error in the original estimate of total reserves for the deposits studied in the mineral belt is small, the methods of exploration and estimation being used are adequate to achieve a realistic appraisal of the total uranium-vanadium reserves of the region.

INTRODUCTION

Since November 1947, the U. S. Geological Survey on behalf of the Division of Raw Materials of the U. S. Atomic Energy Commission has been conducting diamond- and wagon-drill exploration for uranium-vanadium deposits on the Colorado Plateau. Much of this exploration has been in southwestern Colorado, within the area described by R. P. Fischer and L. S. Hilpert (1952) as the Uravan mineral belt (fig. 28). In this belt, most of the deposits are in lenticular sandstone beds in the upper part of the Salt Wash sandstone member of the Morrison formation of Jurassic age. Uranium and vanadium minerals impregnate the sandstone and form roughly tabular bodies that generally parallel the bedding of the sandstone. In places the deposits cut across the bedding at a sharp angle. The deposits are irregular in plan, and they range in thickness from a knife edge to a few tens of feet, averaging a few feet thick. They range in content from only a few tons to many thousand tons. A more complete description of these deposits is given by Fischer (1942).

An integral part of the Geological Survey's exploration program has been the estimation of the reserves of uranium and vanadium in the explored deposits. The individual reserve estimates serve as a basis for the leasing of deposits on Government-controlled land, and collectively are useful as a measure of expectable production.

The uranium-vanadium deposits of the Colorado Plateau are of the type classed by McLaughlin (1939, p. 589–621) as "extramensurate—those difficult to explore and measure much in advance of mining." It must be expected, therefore, that reserve estimates that are based mainly on samples from only a few drill holes would not be highly accurate for individual deposits. The present study has been undertaken to determine the accuracy of the reserve estimates, to investigate the causes of inaccuracy and the possibility of correction of these

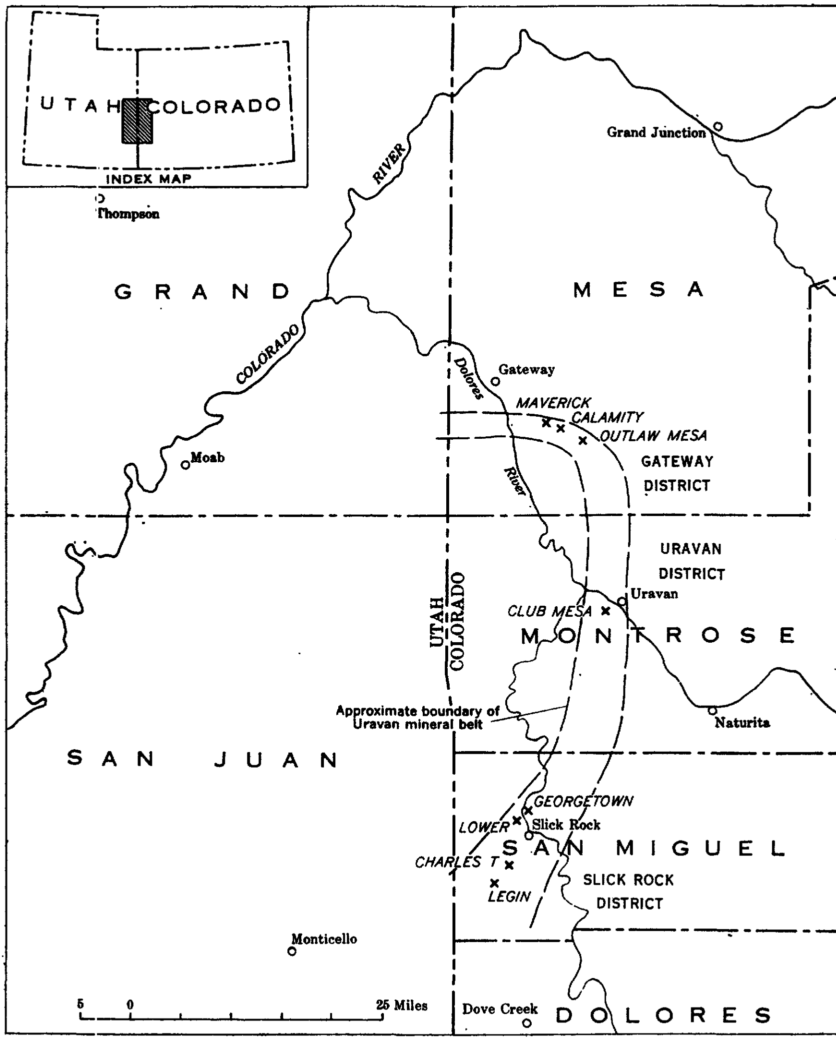

FIGURE 28.—Map of part of the Colorado Plateau showing location of the Uravan mineral belt and of mineral claim groups studied.

inaccuracies, and to determine the significance of the estimates in terms of total known reserves of the region.

METHOD OF STUDY

It is obvious that the accuracy of a reserve estimate can best be determined when the reserve block (the ore body) has been completely mined out. Only then can direct comparison be made between the estimated content and the actual content, as to both tonnage and grade. Very few of the deposits on the Colorado Plateau, for which the Geological Survey has made reserve estimates, have been entirely, or even significantly depleted. In this sense this study is premature. However, interest is in the present content of the deposits, as well as the accuracy of the original estimate, not in a post-mortem knowledge of what the content or accuracy was. The study must take the form, therefore, of a reestimate of the total reserves of the deposit that existed at the time of the original estimate. This reestimate (the revised reserve estimate) includes the production from the deposit since the original reserve estimate plus the estimate of the reserve remaining in the ground. By comparing the revised reserve estimate with the original reserve estimate, an expression of the accuracy of the original estimate is obtained.

Information additional to that available at the time of the original reserve estimate is necessary for a meaningful reappraisal of the reserves in these deposits. For this reason, only those deposits that have yielded, since the original reserve estimate, about 25 percent or more of the tonnage of the original reserve estimate were selected for study. Additional information resulting from drilling done by the mine operator in conjunction with the mining was also available for many deposits. Furthermore, because the production potential of small deposits is not very important, only deposits estimated to contain about 1,000 tons or more of ore were included in this study. These factors resulted in the selection of 30 deposits for reappraisal. These deposits, however, are thought to be typical and to represent a good sample of all deposits for which reserves have been estimated by the Geological Survey.

These deposits were mapped, generally at scales of 1 inch to 40 or 50 feet, to obtain information on extent of mining, habits, thicknesses, and grades of the deposits and ore bodies, and their general trends. This information, plus the additional drilling information, was compiled on maps showing the original information available (drill holes, mine workings, ore-deposit boundaries, and reserve-block locations). On the basis of the additional information, the boundaries of the deposits and the location and size of the original reserve blocks were redefined. Thus the revised reserve blocks include the material in the ground at the time of the original reserve estimate.

In general, experience has shown that after 1,000 to 1,500 tons of ore has been produced from a deposit, or in the case of small (less than 5,000 tons) deposits, after about 25 percent of the ore has been mined, the cumulative grade of the production is a fair representation of the overall grade of the deposit. For this reason, the grade of ore produced was used in many cases as the grade of the reserves in the revised reserve estimate. The validity of this approach appears to borne out by an extremely close correspondence of the average U_3O_8

and V_2O_5 grades of the original reserve estimate for all the deposits studied with the average grade for the production from those deposits.

The mines were mapped in their extent as of December 31, 1952. To correlate with this extent of the mining, figures of production to the same date were used.

DEFINITION OF RESERVES

In 1949, the Geological Survey staff on the Colorado Plateau prepared a statement to define the general philosophy and the rules for the calculation of reserves for the uranium-vanadium ("carnotite") deposits of the Colorado Plateau, in order to obtain a reasonable consistency of reserve calculations made by different geologists and to assist those who would use these figures in interpreting their significance.

The terms "indicated" and "inferred" reserves are applied to the uranium- and vanadium-bearing materials in the deposits that are known from exposures in natural outcrops, mine workings, or drill holes. These reserves are subdivided by thickness and grade cutoffs and the method used in calculating them is explained on pages 136–137.

Known reserves are classed as indicated and inferred. Reserves that might be classed as measured are included with indicated reserves, because the amount of measured reserves that could be calculated within a small limit of error is so small as to be nearly negligible. This is due to the general lack of abundant sample data for individual reserve blocks and the erratic deviations, within short distances, in the thickness and grade of the carnotite ore.

Indicated reserves are those for which the grade is computed from drill-hole samples, exposures in mine workings and natural outcrops, gamma-ray logs, and production data, and for which the tonnage is computed by projection for a reasonable distance on geologic evidence from points of exposure (drill holes, mine workings, and natural outcrops). Inferred reserves are those for which quantitative estimates are based largely on broad knowledge of the geologic character of the deposits, and for which there are few, if any, samples or measurements.

METHOD OF CALCULATION

Reserves are not classified according to their availability for mining, although consideration is given to current mining and milling practices in selecting the higher grade and thickness cutoffs. This is done to obtain figures for a category of reserves that will express as nearly as possible the tonnage and grade of the material that actually might be mined from these deposits under present conditions.

Both chemical data from assay of drill cores and gamma-ray data from probing of drill holes are used in classification of the ore-bearing rock as to thickness and grade.

Thickness cutoff.—Mining practices differ from place to place in the region as well as with individual operators, but under present conditions most ore bodies of average grade are being mined to where they pinch to a layer about 1 foot thick. Reserves, therefore, are calculated with a thickness cutoff of 1 foot. Layers of material less than 1 foot thick are mined in places if the grade is high. The tonnage of minable material less than 1 foot thick is small with respect to the total reserves, and for that reason reserves less than 1 foot thick are calculated in a separate category.

Grade cutoffs:—The deposits contain two metals of economic value, uranium and vanadium. Within the deposits, the two metals are so erratically distributed that a single sample, such as obtained from a drill hole, is not necessarily representative of the grade or metal ratio of the material near the point sampled. Knowing this by experience, the miner will drive to a drill hole that shows a good value in vanadium even though the uranium content of the sample might be negligible. Thus, the material in the vicinity of this sample must be classed as a reserve, even though the sample shows a value for only one metal. Under 1953–54 price schedules, the vanadium content of the ore represents an appreciable part of the ore's market value. Both metals, therefore, must be considered in reserve appraisals and in selecting grade cutoffs.

Reserves 1 foot or more thick are classified by two grade cutoffs. The higher cutoff used—0.10 percent U_3O_8 or 1.0 percent V_2O_5—corresponds to the AEC purchase cutoff for uranium and the approximate cutoff used at the government-owned mill at Monticello, Utah, in selecting ore for treatment to extract vanadium. Reserves also are figured on a lower cutoff—0.05 percent U_3O_8 or 0.50 percent V_2O_5—on the possibility that conditions in the future might demand or permit the mills to accept low-grade ore.

Calculation of tonnage.—The method used for calculating the volume, and hence the tonnage, of a reserve unit 1 foot or more thick differs with the geologic interpretation of the form of the deposit. Some deposits are roughly tabular or lenticular, so that projections can reasonably be made between drill holes, and the average thickness of the drill-hole samples that can be combined within a specified grade class can be assumed to be the average thickness of the reserve unit. Other deposits consist of small bodies of ore of minable thickness, connected by layers of mineralized sandstone that are too thin to mine. Reserves are estimated by assuming that each drill hole in ore indicates a single minable body that is comparable in tonnage to the average size of the ore bodies that have been mined nearby, or that the deposit contains a comparable tonnage per unit area to that of a deposit that has been mined nearby.

The tonnage of indicated reserves is computed by projection for a reasonable distance on geologic evidence. The distance that indicated reserves are projected, both between and beyond drill-holes and other sample points differs with the geologic habits of the deposits; the limits of projection used are specified. Reserves are classed as inferred rather than indicated if they are projected farther than the limits chosen for the indicated class. Inferred reserves are projected to the assumed limits of the deposit, as assumed by geologic evidence and interpretation; no arbitrary limit is placed on the distance of projection.

Although a single drill hole in ore obviously permits the designation of some tonnage of indicated reserves, there is no reasonable basis for projecting an indicated reserve block more than a few feet from a single hole. Rather than calculate such a separate indicated reserve block, or assign a small arbitrarily selected amount of indicated reserves to a single hole, the reserve block is projected to its assumed limits and the ore calculated and classed as inferred.

A constant of 14 cubic feet per ton is used to calculate tonnage.

Calculation of grade.—The grade of indicated reserves in a single block is calculated by weighting the assay grades by lengths of the samples. If the deposit has been mined in part, the grade of the ore produced is also considered in establishing the grade of the adjoining reserve block. In reserve blocks containing only one or two drill holes, however, if the core assays are appreciably higher than the average grade of the ore mined nearby, it may be assumed that the drill penetrated abnormally high-grade parts of the body, and an estimated grade may be assigned. The grade of the samples in an inferred block is considered, but is used in conjunction with the grade of production from nearby mines, or from the area as a whole.

Strict grade cutoffs are used in calculating reserves 1 foot or more thick. Except as noted in the following paragraph, no material belonging to a class with a lower grade cutoff is included with material of a higher cutoff class, even though the weighted average grade of the whole is above the cutoff grade of the higher class.

In mining, layers of waste, or of low-grade mineralized material, less than 1 foot thick, would probably be blasted with the enclosing layers of ore. Some of this material might be picked out by hand, but most of it would go to the mill with the ore. If the aggregate thickness of this interbedded ore and waste is 1 foot or less thick, it is included in calculating reserves, thereby increasing the thickness of ore, but decreasing the grade proportionately. This ore is classed according to the grade of the weighted average. If the waste is more than 1 foot thick, it probably would be blasted separately from the ore layers in mining, and thus ore layers more than 1 foot apart, with waste or low-grade material between, are calculated as separate ore bodies.

CHARACTER OF DATA

The original reserve estimates were based largely on drill-hole data, supplemented in some cases by exposures in mine workings and natural outcrops. In general, the amount of information available for the reserve estimate is a function of the drill-hole spacing. A major objective of the Geological Survey's exploration work is the discovery of ore deposits, and the estimation of their size, in terms of reserves that are not more precise than the indicated class. At this level of precision, the spacing of drill holes is designed to outline the limits and to indicate the order of magnitude of the deposits with a minimum of drilling. The drill holes were spaced mostly at 50- to 100-foot intervals; in a few places holes were as much as 200 feet apart.

Chemical assays for U_3O_8 and V_2O_5 are available for all the mineralized rock cored in the drilling. Although core recovery differs from hole to hole, as well as from one lithologic unit to another within a single hole, the average core recovery for mineralized rock is probably about 80 percent. The core recovery for barren sandstone is usually better and in many units is 95 to 100 percent. The position and thickness of the mineralized rock, therefore, can often be determined with considerable accuracy, despite core loss within the unit. The grade can be seriously distorted by core loss, however, as the richer material is commonly fine and friable. A partial correction for the loss of the richer material may be made through the use of gamma-ray data obtained by probing the drill holes.

The revised reserve estimates are invariably based on additional information. The habits of the deposits can be studied in new or expanded mine workings, the boundaries of the deposit are exposed in places, additional drilling in many cases is available so that the extent and average thickness of the deposit are better known, and the production records give a strong basis for the assignment of grades to the unmined ore.

Generally, the data available from additional drilling done by the mine operator is less reliable than that from Geological Survey drilling. Drill-hole locations may be less accurately recoverable, chemical assays on the core are usually lacking, and data on the position and thickness of the mineralized material, both in core and noncore drilling, may be somewhat less reliable. Many of these disadvantages, however, are at least partially compensated by the greater density of drilling. In some cases a major weakness exists in the production record. Frequently the ore from several deposits on a claim, or a group of claims, is grouped and attributed to a general area, rather than to a specific deposit. It thus becomes impossible to assign the production accurately to the individual deposit, and the reliability of the revised reserve estimate is weakened thereby.

ACCURACY OF ORIGINAL ORE RESERVE ESTIMATES

The basic tool in the assessment of the accuracy of the original estimate is the realization ratio, the ratio of the revised estimate to the original estimate. Realization ratios have been calculated for each deposit (or each case studied) in terms of tonnage ratio, grade ratio of both U_3O_8 and V_2O_5, and content ratio of both U_3O_8 and V_2O_5. Ratios have also been calculated for each large group of deposits, for each district, and for all 30 deposits studied in the mineral belt.

Errors in the original reserve estimates decrease generally, as the number of deposits included in the estimate is increased, due to compensation of individual errors. Estimates on individual deposits range widely in accuracy, from large overestimates to very large underestimates. Estimates for the mineral belt, however, are well within the limits of accuracy expected, constituting a small underestimate for tonnage, contained U_3O_8, and contained V_2O_5. The progression is orderly, the error is greatest on individual deposits, less on large groups of deposits, still less by districts, least for the entire mineral belt.

For the entire mineral belt, this study indicates that the tonnage of the revised estimate is about 15 percent more than originally estimated. There is also about 15 percent more U_3O_8 and about 20 percent more V_2O_5 in the revised reserves than in the reserves originally estimated. Expressed in terms of grade, in the revised reserves the average U_3O_8 grade is the same as the original estimate and the average V_2O_5 grade is slightly higher than the original estimate, differing by less than 2 pounds per ton.

The Geological Survey's reports to the Atomic Energy Commission on carnotite reserves have included the following statement—

> Because of the variations in thickness and grade of ore and the scarcity of sample data, the indicated reserves in any single reserve block might actually amount to as much as twice or as little as one-half the calculated tonnage. The limit of error of the total tonnage for several blocks, however, is apt to be considerably lower, perhaps not more than 25 percent of the calculated tonnage. The limit of error in the tonnage figures for inferred reserves, of course, is apt to be higher than for the indicated reserves. The possible limit of error in the calculated or estimated grade for both indicated and inferred reserves probably is somewhat smaller than the possible limit of error in the tonnage figures.

TONNAGE

The data presented in figure 29 show that the quoted statement above is substantially correct. The comparison shows that all of the deposits studied actually contained (according to the revised esti-

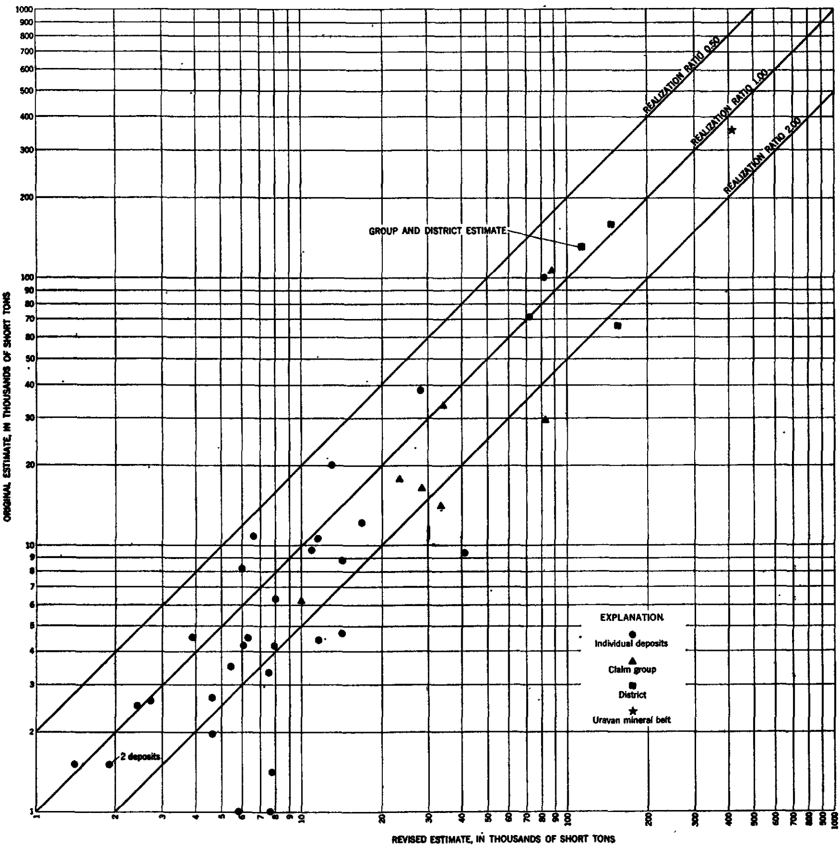

FIGURE 29.—Graph showing variation in accuracy of original tonnage reserve estimates.

mate) more than one-half the originally calculated tonnage of both indicated and inferred reserves. The only deviation from the statement is that a little over one-quarter of the deposits appear to contain more than twice the amount of indicated and inferred reserves.

The limits of error are smaller for groups of deposits than they are for single deposits. In four of the eight large groups, the realization ratios for tonnage of indicated and inferred reserves fall between 0.8 and 1.3. The other four all contain from 1½ to a little less than 3 times the originally calculated tonnage of indicated and inferred reserves.

Considered by districts, the tonnage realization ratios for two of the three districts are 0.8 and 0.9, the third contains over twice as much reserves as originally calculated. For all the deposits studied in the mineral belt the tonnage realization ratio is about 1.15.

GRADE

In general, the range of error and the limit of error in U_3O_8 and V_2O_5 grades (figs. 30 and 31) are considerably smaller than those for the tonnage of ore (fig. 29). On an individual basis, almost three-quarters of the deposits have U_3O_8 grade realization ratios between 0.5 and 1.5, and seven-tenths of the deposits have V_2O_5 grade realization ratios between 0.75 and 1.25. By groups, the U_3O_8 realization ratios of six of the eight groups are between 0.5 and 1.5 (a seventh has a ratio of 1.6) and five of the eight groups are between 0.75 and 1.25. The V_2O_5 realization ratios of all eight groups are between 0.85 and 1.1, and for six of the eight groups are between 0.95 and 1.05. By districts, both the U_3O_8 and V_2O_5 realization ratios are between 0.85 and 1.1. For all the deposits studied in the mineral belt, the U_3O_8 and V_2O_5 realization ratios are 1.0 and 1.05 respectively.

VARIATION WITH SIZE OF DEPOSIT

A study was made of the accuracy of the original reserve estimates grouped by size of the ore deposits. (See table below and figs. 30 and

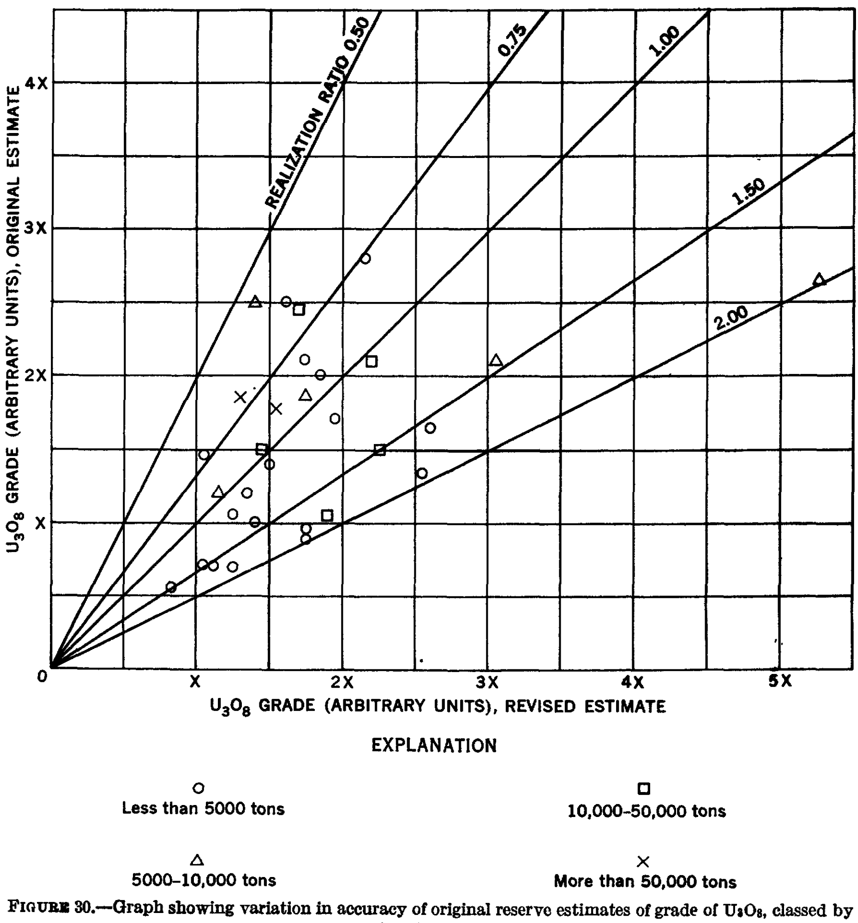

FIGURE 30.—Graph showing variation in accuracy of original reserve estimates of grade of U_3O_8, classed by size of deposit.

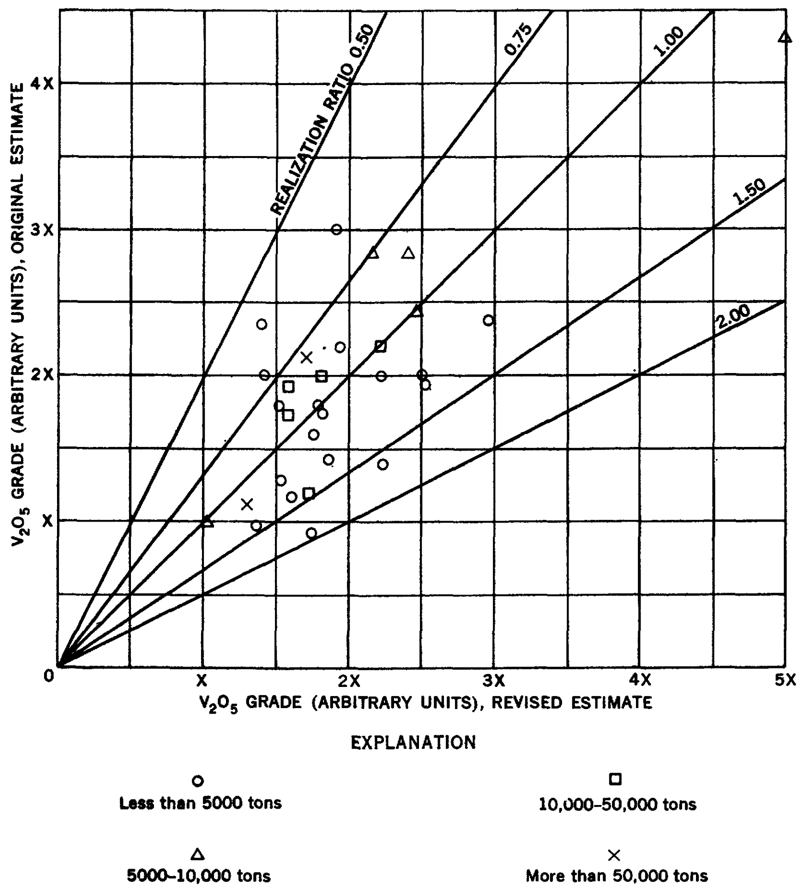

FIGURE 31.—Graph showing variation in accuracy of original reserve estimates of grade of V_2O_5, classed by size of deposit.

31.) The deposits were classed into four categories—less than 5,000 tons, 5,000–10,000 tons, 10,000–50,000 tons, and more than 50,000 tons. The distribution of deposits in these classes is such that there are probably sufficient cases in the first three categories to warrant some generalizations. With only two cases in the fourth category, it is not possible to make significant generalizations.

On the basis of the size of the reserve block as originally estimated, deposits thought to be in the less than 5,000 ton class are underestimated in tonnage in about nine-tenths of the cases, and underestimated in both U_3O_8 and V_2O_5 grade in about two-thirds to three-quarters of the cases. In the 5,000–10,000 ton class, tonnage is underestimated in four-fifths, and both U_3O_8, and V_2O_5 grades are underestimated in three-fifths of the cases. In the 10,000–50,000 ton class tonnage is underestimated in two-fifths, U_3O_8 grade in three-fifths, and V_2O_5 grade in two-fifths of the cases. The relative amount of error represented by the average realization ratios for each class decreases from the less than 5,000 ton class to the 10,000–50,000 ton class.

Variation in accuracy of original estimates of reserves, grouped by size of deposit.

Deposit class	Number of cases	Original reserve estimate, in short tons [1]	Revised reserve estimate, in short tons [1]	Realization ratios [2]				
				Tonnage	Content		Grade	
					U_3O_8	V_2O_5	U_3O_8	V_2O_5
Less than 5,000 tons	18	50,740	103,900	2.05	2.45	2.25	1.20	1.10
5,000–10,000 tons	5	42,160	80,300	1.90	2.05	1.85	1.05	.95
10,000-50,000 tons	5	91,610	76,200	.85	.90	.80	1.10	.95
More than 50,000 tons	2	169,875	154,100	.90	.75	.85	.80	.95

[1] Includes indicated and inferred reserves.
[2] Ratio of revised estimate to original estimate.

VARIATION WITH DENSITY OF DRILLING

An analysis was made of the accuracy of the original reserve estimates grouped by the density of drilling. (See table below and fig. 32.) As is to be expected, denser drilling permitted more accurate reserve estimates. The density of drilling by the Geological Survey has been described briefly on page 138. Most of the deposits drilled by the Geological Survey in the mineral belt were explored under a drilling plan consisting of four drill holes at a spacing of 50 feet around the discovery hole, followed by other drill holes at a spacing of 100 feet (pl. 7*A*). Other deposits were explored by six drill holes at a spacing of 50 feet around the discovery hole, followed by other drill holes at the same spacing, with additional drilling at a spacing of 100 feet on some deposits (pl. 7*B*).

Of the 30 cases studied, 25 fall into these two classes of density of drilling; there are 18 cases of Type B drilling to only 7 cases of Type A drilling. The Geological Survey has used three other drilling plans, one of which is illustrated in plate 7*C*, but with only 5 deposits in these 3 classes, generalizations are not significant. In 4 of the 7 cases where Type A drilling information was used, the revised reserve estimate for tonnage is more than twice the original, and the range is up to 8 times the original. Where Type B information was available, the revised reserve estimate was more than twice the original in only 2 of the 18 cases, and the range was up to only 3 times. The data also show a general increase in accuracy for both U_3O_8 and V_2O_5 grades in the cases for which more information is available.

Variation in accuracy of original estimates of reserves, grouped by density of drilling and size of deposit

[See also figure 32]

Drilling plan and deposit class	Number of cases	Original reserve estimate, in short tons	Revised reserve estimate, in short tons	Realization ratios				
				Tonnage	Content		Grade	
					U_3O_8	V_2O_5	U_3O_8	V_2O_5
Type A:[1]								
Less than 5,000 tons	5	11,400	31,100	2.75	4.05	2.55	1.45	0.95
5,000-10,000 tons	2	18,080	55,400	3.05	2.35	2.75	.75	.90
Totals and weighted averages	7	29,480	86,500	2.95	2.70	2.70	.90	.90
Type B:[2]								
Less than 5,000 tons	11	34,110	55,300	1.60	2.00	1.95	1.20	1.20
5,000-10,000 tons	3	24,080	24,900	1.05	1.75	1.15	1.70	1.10
10,000-50,000 tons	4	71,610	63,200	.90	1.00	.85	1.10	.95
Totals and weighted averages	18	129,800	143,400	1.10	1.35	1.20	1.20	1.10
Type C:[3]								
Less than 5,000 tons	1	830	5,900	7.10	10.20	9.00	1.45	1.25
10,000-50,000 tons	1	20,000	13,000	.65	.65	.60	.95	.90
Totals and weighted averages	2	20,830	18,900	.90	.75	.85	.85	.95
Type D:[4]								
Less than 5,000 tons	1	4,400	11,600	2.65	2.80	3.10	1.05	1.15
More than 50,000 tons	1	71,500	72,200	1.00	.70	.80	.70	.80
Totals and weighted averages	2	75,900	83,800	1.10	.80	.90	.75	.90
Type E:[5]								
More than 50,000 tons	1	98,375	81,900	.85	.75	.95	.90	1.10
Totals and weighted averages	1	98,375	81,900	.85	.75	.95	.90	1.10

[1] One cycle of four drill holes around discovery hole, at 50-foot distance; additional holes at 100-foot intervals.

[2] One or more cycles of six drill holes around discovery hole, at 50-foot distance; additional holes at 100-foot intervals.

[3] One or more cycles of drill holes around discovery hole at 100-foot distance; additional holes at 100-foot intervals.

[4] One or more cycles of drill holes around discovery hole at 100-foot distance; additional holes at 150- to 200-foot intervals.

[5] Drill holes 50 to 100 feet apart, along lines 200 feet apart

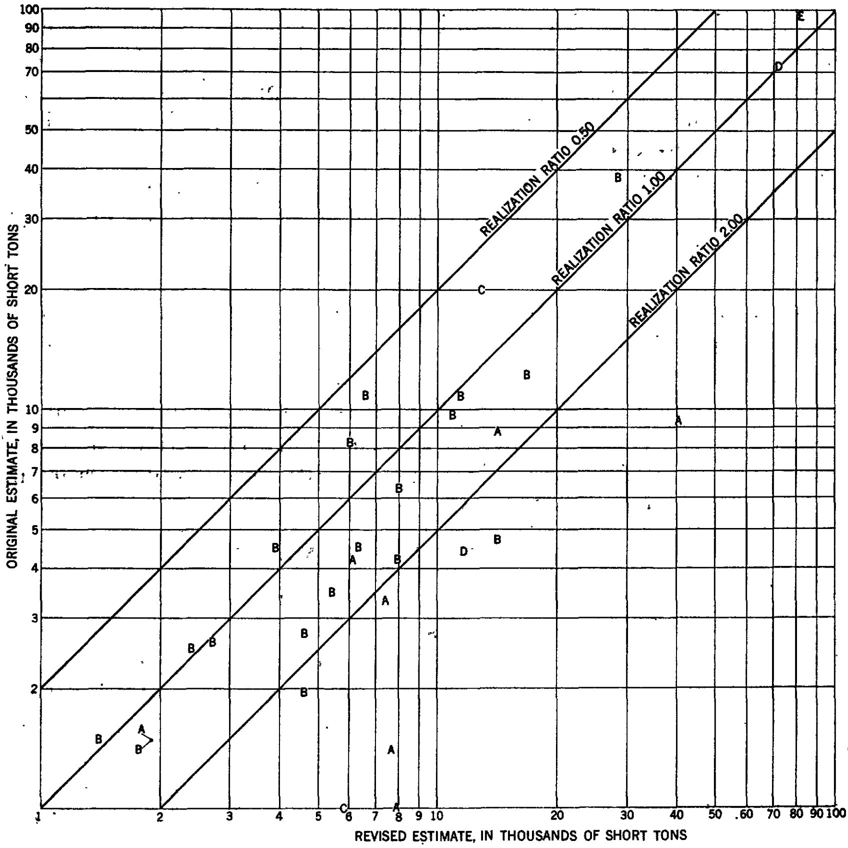

FIGURE 32.—Graph showing variation in accuracy of original tonnage reserve estimates, for deposits classed by density of drilling. (See table on page 144 for explanation of letters.)

CAUSES OF INACCURACY

Both the original and the revised reserve estimates are subject to error. In general, the causes of error differ for the type of estimate, but one major cause of error is common to both; the restricted number of point of observation (sample points) on which the estimates are based.

ORIGINAL RESERVE ESTIMATES

The density of sampling is the basic source of error in the original reserve estimates. In general, the drilling is sufficient to indicate the approximate outline and extent of the ore deposit, but in specific cases, the ore bodies may extend between barren or weakly mineralized drill holes for a significant distance (pl. 7*A* and *D*). The drill holes may not adequately sample, however, or may not even intercept the parts of the deposit that constitute the ore bodies (pl. 7*A*).

The drill-core samples, in addition, may not be representative of the average thickness of the ore body or of its average grade. Core loss in drilling may result in significant misinterpretations of the thickness of the mineralized rock. In addition, the more richly mineralized rock is generally softer and more friable and hence is more subject to grinding and disintegration. Core loss, therefore, is frequently concentrated in the more richly mineralized rock, so that the apparent grade of the sample is less than the true grade.

In most cases, the concept of the deposits (and ore bodies) as uniformly tapering tabular layers, essentially parallel to the bedding of the host sandstone, is used in calculating the reserves (pl. 7*B*). Other limiting conditions are also assumed; for example the edge of the deposit is assumed to be midway between a sample point in barren rock and a sample point in mineralized rock. Deviations in form, shape, and habit from these idealized conditions introduce errors in the reserve estimate (pl. 7*A* and *C*).

REVISED RESERVE ESTIMATES

The revised reserve estimates also have their basic source of error in the restricted number of points of observation. The influence of this distribution is less pronounced than in the case of the original estimate, as the prerequisite to the revised estimate is additional information. Additional drilling by the operator frequently outlines both the deposit and the ore bodies far better (pl. 7*D*). The mine workings permit a more accurate assessment of the habits of the deposit, and the concentration and size of the ore bodies (pl. 7*B* and *C*). In many cases, however, the thickness and grade data available from the operator's drilling is less reliable than data from the Geological Survey's drilling, because of difference in objectives, technique, and a common lack of chemical assay data.

Major use is made of the production data in revising the estimate of tonnage and grade given in the original reserve estimate. Several opportunities for error in the revised estimate may result from the character of the production data. In many cases the production record cannot be broken down with sufficient reliability to permit the accurate assignment of production to individual deposits. In such cases, the production must be estimated for each deposit, or the deposits must be grouped and a combined depletion estimate for the group must be made. It is obvious that additional uncertainties are introduced in either case, both for tonnage and for grade. Such uncertainties, however, are thought to be small generally, and certainly do not invalidate the overall picture presented here.

Nearly all the mine operators attempt to hold to a shipping grade above 0.20 percent U_3O_8, because the AEC pays bonuses for ore above this grade. Although the grade cutoff used by the Geological Survey in its estimates is 0.10 percent U_3O_8 (the lowest grade that is being purchased by the AEC), the average grade of the ore at this cutoff is generally above 0.20 percent U_3O_8. Thus the material mined and that for which reserves are estimated are comparable. One other factor affects the use of the production data—the dilution of ore by waste. The effect of this source of error is relatively minor, as the methods of reserve estimation used by the Geological Survey make allowance for a certain amount of dilution.

CONCLUSIONS

The accuracy of the Geological Survey's estimates of total indicated and inferred reserves, for the 30 cases studied in the Uravan mineral belt, fall well within the defined limits of error for indicated reserves alone, and indeed fall almost entirely within the defined limits of error (20 percent) for measured reserves. The limits of error, and the range in error, are greatest for reserves on individual deposits, less for reserves on groups of deposits, and still less for reserves of districts. The inaccuracies involved are largely compensating, to the point of very little error if a sufficient number of deposits are considered.

The 30 cases considered in this study represent a fair sample of all deposits on which the Geological Survey has made reserve estimates. They include deposits ranging from less than 1,000 tons of reserves to more than 50,000 tons; deposits where all the information came from drill-hole samples and deposits where a larger part of the information came from extensive mine workings; and deposits where the drill-hole samples came from close-spaced, medium-spaced, and relatively wide-spaced holes, or any combination of these. As such, the realization ratios determined for the total group of cases studied can be applied with reasonable confidence as correction factors to the total of the indicated and inferred reserves estimated for all the deposits discovered or explored by the Geological Survey. These realization ratios are about 1.15 for the tonnage of ore, 1.15 for the amount of contained U_3O_8, and 1.20 for the amount of contained V_2O_5. The original grade estimate for U_3O_8 is the same as the revised estimate, and the original grade estimate for V_2O_5 differs from the revised estimate by less than 2 pounds per ton.

Correction factors cannot be applied to the individual reserve estimates. On a numerical basis, in about two out of every three cases the tonnage of reserves was underestimated; the range of the realization ratios is from about 1.0 to 8.0. However, in two-thirds of the cases where the tonnage of reserves was underestimated, the range of the realization ratios is from 1.0 to only 2.0. The range of the realization ratios for overestimated reserves is from 0.6 to nearly 1.0. Thus any single correction factor designed to reduce the error of underestimate will increase the error of overestimate in one of every three cases. The range and distribution of error for the estimates of grade and amount of U_3O_8 and V_2O_5 are similar to those for total tonnage of ore, and these errors, as well, cannot be remedied by applying single correction factors to the individual deposits.

The realization ratios for each group of deposits studied can be applied with a measure of certainty to the total indicated and inferred reserves of all the deposits in that group. The reliability of the ratios increases with the number of cases used in determining the ratios. Still more reliance can be placed on the realization ratio for the reserves compiled by districts.

One of the Geological Survey's major objectives in the exploration work is the appraisal of the uranium-vanadium resources of the Morrison formation on the Colorado Plateau. The study indicates that the accuracy of the appraisal of the total known reserves is good. As such, the methods of exploration and estimation being used are adequate to achieve the desired objectives.

Within the framework of the exploration done by the Geological Survey, increased accuracy in the estimates can only be obtained by increased knowledge of the geologic habits of the deposits, and this is largely dependent on the increase in the amount of information available at the individual deposit level—supplied by additional and more closely spaced drilling. So long as the major interest is in the overall appraisal, the present methods are adequate. Increased accuracy on individual deposits will increase the accuracy for each succeeding grouping of deposits, but the significance of this increased accuracy decreases for each succeeding grouping as the amount of error involved under the present methods also decreases markedly.

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