Uranium

Sub-committee Members

Alain Mainville, Cameco Corporation, Saskatoon
Tom Pool, Nuclear Fuels Corporation, Denver
E.A.G. (Ted) Trueman, Trueman Consulting Ltd., Denman Island, B.C.
Donald M. Ward, B.A.Sc., retired, Crofton, B.C.
Neil D.S. Westoll, Neil D. S. Westoll & Associates Ltd., Oakville, Ontario

Preamble

The distinguishing aspect of uranium, and its associated daughters, is radioactivity. This characteristic is highly beneficial in assay determination, grade control and ore sorting, although it does impose environmental, health and safety concerns. Exploration, development and mining of uranium are tightly regulated activities.

The General Guidelines for other metals, outlined in the Best Practice Guidelines (June 24, 2002 draft) are also applicable to uranium deposits. However, because of the radioactive nature of uranium, and in some cases the amenability of this metal to In Situ Leach (ISL) mining methods, additional guidelines are appropriate.

Qualified Person

A QP must be familiar with the radioactive nature of uranium, thorium and potassium minerals, and the characteristics of the radioactive decay series, which result in various uranium isotopes and other daughter products. A QP must also be familiar with equipment and techniques used in acquiring radiometric data, and with methods for Quality Assurance (QA) and Quality Control (QC) specifically applicable to uranium. Definitions Disequilibrium: An imbalance between the uranium content and the radioactivity emitted by a given volume of mineralized rock. This imbalance is caused by either differential mobilization of the more soluble uranium from the deposition site, relative to its daughter isotopes, or by a lack of time for the accumulation of the daughter isotopes to reach a state of equilibrium after the uranium has been deposited. Generally when the decay series is in equilibrium the gamma plus beta radiation is proportional to the amount of uranium present.

Disequilibrium is particularly prevalent in sandstone-hosted uranium deposits within a dynamic hydrologic regime, where mobilization of the uranium out of the deposition site results in an overestimation of the uranium content, based on radiometric measurements. Conversely, in a geologically young environment, a deficiency of daughters relative to uranium will cause an underestimation of uranium content based on radiometric methods. The degree of Disequilibrium may vary from place to place within a deposit. Equivalent Assay: Determination of uranium content by radiometric methods. The validity of Equivalent Assays must be demonstrated with chemical assay determinations. Where employed, equivalent uranium determinations should be reported and appropriately illustrated in the database (e.g. eU_3O_8).

In Situ Leach (ISL): Removal of the valuable components of a mineral deposit without physical extraction of the rock (see Selected Reference, World Nuclear Association, 2001). The orebody must be permeable to the leach solutions and situated such that ground water in proximity will not be contaminated by mining operations.

K Factor: A factor determined for each radiometric logging apparatus in order to Standardize Equivalent Assays. Each logging unit, probe etc. must be individually calibrated to determine its own K Factors. K Factors can be determined from specially designed calibration pits, reference sources or cored holes. If cored holes are utilized, core recovery must be close to 100%, and core assays must be representative of the full range of assay data.

Resource Database

Radioactivity associated with uranium provides additional data sets that can be used to characterize a deposit. Radiometric data may form much of the grade information from which a MRMR estimate is compiled. QC for radiometric data should be as rigorous as that for chemical assays from an analytical laboratory. Data should be clearly identified as to its derivation (e.g. radiometric, chemical analysis, etc.). QC of radiometric data can be achieved only through a rigorous, ongoing program of calibration of individual assaying and logging tools.

A QP will understand that the process of calibration of these tools is closely akin to both the process and the importance of check assays for a chemical laboratory. Radiometric data must be validated against chemical assay data in order to: 1) ensure proper calibration of assaying and logging tools, and 2) determine the degree to which Disequilibrium may be present. Best Practice dictates that an overall factor for Disequilibrium should be compiled for each deposit and adjusted as additional information is obtained. Such factors are recognized and accepted in the industry. Disequilibrium problems may be overcome through the use of direct measuring methods such as neutron activation or prompt- fission neutron logging tools. Such use, however, does not obviate the need for data validation through chemical assays. Radiometric assaying of rock samples (e.g. core, muck, channel, etc.) allows for fast and inexpensive uranium determinations once appropriate procedures are established and instruments are calibrated.

As is done in preparation for chemical assaying, samples are crushed, pulverized, homogenized, and representative fractions taken. Standard samples are run, and background readings are taken on a regular basis to ensure that precision is maintained. Calibration samples, blocks or pads are frequently employed. Radiometric assaying equipment, provided that it has been properly calibrated, can also be employed to provide immediate grade determinations by scanning ore faces, muck piles, conveyor belts, etc. in operating mines. Radiometric data are often acquired by down-hole electric logging techniques and may be either indirect, as in the form of gamma logging, or direct, as in the form of prompt fission neutron logging. Down-hole logging plays a vital role because it allows for use of fast, lower cost drilling methods, such as percussion or rotary drilling, and the continuous nature of the data also provides a complete profile where core recovery is poor or nonexistent.

If equipment allows, both electronically recorded data files and graphical representations of radiometric data should be collected. Equivalent Assays from radiometric logging may be calculated from either electronically recorded data files or from digitization of graphical representations; however, once a method is chosen it should be used exclusively. When the precision of Equivalent Assay data has been demonstrated, the Equivalent Assay data may be merged with chemical assay data from drill core in the database for the MRMR estimate. Data from non-core drill holes may provide a considerable portion of the database; however, in order to satisfy QA/QC of radiometric data, and provide geological information for deposit interpretation, core drilling is also required.

Representative core or rock samples must also be available from throughout the deposit in order to provide an accurate determination of density for tonnage estimation. All cored holes should be radiometrically logged to ensure continuity within the database and for calibration of logging equipment. All data must be clearly identified as to the source of the information (e.g. diamond drill core versus 50 percussion holes; radiometric versus chemical analyses).

The drilling process often contaminates a portion of a drill hole, down-hole from a uranium intersection, through smearing of cuttings. Dissemination of radon in the hole and mass effect of high- grade intersections may also inflate Equivalent Assays. These characteristics can result in the grade and thickness of an intersection being overstated during radiometric probing and results must be adjusted accordingly. The QP must be cognizant of these problems and ensure that appropriate QA measures are incorporated. Probe measurements are sensitive to a number of factors such as presence of rods and/or casing in the hole, thickness and types of metal in rods and casing, hole diameter, medium (air or water), logging speed, and probe characteristics (e.g. diameter, type, dead-time & measuring interval). Therefore, the names, models and serial numbers of all equipment used, and the particulars of each hole, should be recorded on drill hole logs.

In addition, factors for the above sensitivities should be determined, maintained, and applied to obtain corrected results. Each logging unit, probe etc. must be individually calibrated to determine its own K Factor. Equivalent Assays determined from different units may then be merged into the database for a MRMR estimate. Holes are usually logged from the bottom up, after slowly lowering the probe in order to identify radioactive sections, to maintain optimum logging speed and zero the depth measurements. Radiometric logging of bore holes primarily measures gamma rays due to their higher penetration properties than beta or alp ha particles.

Geological Interpretation & Modeling Like other deposits of metallic minerals, uranium occurs in many different geological environments. The QP must identify the style of mineralization; determine a geological model and, fundamental to a MRMR estimate, ensure a valid geological interpretation of the mineralized zone. In this respect there is no significant difference between uranium deposits and other metal deposits. However, the geological setting of a uranium deposit may also be of importance in determining if Disequilibrium exists or in identifying potential for ISL exploitation. Graphical representations of radiometric logs are invaluable for geological correlation between drill holes.

Mineral Resource Estimation

The General Guidelines of the Estimation of Mineral Resources and Mineral Reserves document apply to uranium deposits. In addition, the following guidelines apply. The value of a commodity is obviously fundamental to a resource estimate. However, the price of uranium at any given time may not be known with accuracy as most uranium is sold under long-term, confidential contracts. A spot price, which generally represents the minimum prevailing market value, is readily available. Other sources, such as the International Atomic Energy Agency (Red Book), Government of Saskatchewan Mineral Statistics Yearbook, the Euratom Supply Agency, and the U.S. Energy Information Administration, provide indications of recent contract prices.

The QP should ensure that the uranium price used in a MRMR estimate is in line with available pricing information. Some unconformity-related deposits, such as those in northern Saskatchewan, are unusually high- grade and contain huge quantities of uranium, but are volumetrically small. As such they require particular attention with respect to certain parameters (e.g. drill hole spacing, density contrasts, and safety precautions) relative to lower grade sandstone, pegmatite, conglomeratic or calcrete hosted deposits.

ISL mining of uranium is increasing in importance and requires somewhat different treatment in MRMR estimates from conventional production methods. Uranium deposits amenable to ISL methods present special situations in that some parameters (e.g. tonnage, minimum mining width, cut-off grade, dilution, etc.) are not necessarily applicable in the same form as for conventional mining. Other parameters, especially recovery, are of special importance. ISL methods of uranium mining necessarily incorporate additional physical and chemical parameters that are not germane to open pit and underground mining. These include: 1) permeability of the mineralized horizon; 2) hydrologic confinement of the mineralized horizon; 3) amenability of the uranium minerals to dissolution by weak alkaline or acidic solutions; and 4) ability to return groundwater within the mined area to its original baseline quality. It is common practice in MRMR estimates for ISL projects to use a grade times thickness (GT) contour method. This method is based on the product of mineralization grade and true thickness, indicated for each major intercept within the mineralized horizons. A minimum GT cut-off, used in much the same way that a grade cut-off is established for conventional mining operations, should be reported.

MRMR estimates for deposits amenable to ISL methods should be reported in terms of quantity, quality and anticipated recovery. This can be achieved by reporting, in addition to the contained uranium and anticipated recovery, either: 1) deposit area, average thickness and average GT; or 2) tonnage, average grade and average GT. Recovery may be reported either as quantity of recoverable uranium or a percentage of the estimated contained uranium. It should be noted that it has been common practice to report ISL MRMR as quantity of contained U3O8 only, but this practice is not transparent and is not considered appropriate. If available data are insufficient to determine a recovery factor, it is appropriate to point out that recovery in similar deposits is commonly in the order of 60-70%, and could be significantly lower.

Best Practice in ISL MRMR estimation will incorporate significant quantities of hydrologic and geochemical data. In that ISL methods are not familiar to many in the mining industry; it would be good practice in reporting a MRMR estimate to fully discuss all parameters that might affect exploitation of the deposit. If there is an operating mine with similar geological features to a deposit under study, conventional or ISL, and the parameters used for MRMR estimation at the operating mine are known, it would be beneficial to compare the two sets of parameters.
Quantifying Elements to Convert a Mineral Resource to a Mineral Reserve By weight, natural uranium contains only 0.711% 235U, the “active” isotope in nuclear reactions; the remainder is largely 238U with minor 234U. Instances of deviations from the 235U value of 0.711%, the result of natural fission reactions in high- grade deposits, are rare, but do occur. Deviations from the normal 234U value of about 55 micrograms 234U per gram total U are common due to differential solubilities of the isotopes, particularly in low-grade sandstone deposits, and are of increasing concern to the industry because of radiological implications in fuel fabrication. Best Practice calls for isotopic analysis for 235U and 234U in new districts, as deviations will impact marketability.

Mineral Reserve Estimation
In estimating a Mineral Reserve, the preceding guidelines for estimating a Mineral

Resource and the General Guidelines of the Estimation of Mineral Resources and Mineral Reserves document apply.

Reporting

The QP reporting on a MRMR estimate of a uranium deposit should make the reader aware of database limitations and special economics considerations. With respect to the database, the use of radiometric determinations, types of equipment employed, possible Disequilibrium, drill hole contamination, and any other pertinent characteristics should be clearly elucidated. Economic considerations with respect to political concerns, permitting, pricing, supply/demand projections, transportation and marketing may be of special significance for a uranium project.

In order to avoid errors in conversion, a majority of committee members favored reporting of uranium MRMR in standardized units of pounds U3O8. Reconciliation of Mineral Reserves In reconciling a Mineral Reserve estimate with mine-mill production, the General Guidelines of the Estimation of Mineral Resources and Mineral Reserves apply. The production life of each individual ISL well pattern is relatively short, typically 6-18 months, and most of the uranium is recovered within the first six months. The production recorded for a well pattern should be compared to the Mineral Reserve estimated for that portion of the deposit and used to reconcile the total Mineral Reserve estimate for the deposit.

Selected Reference

World Nuclear Association, “In Situ Leach (ISL) Mining of Uranium”, Information and Issue Briefs, November 2001, http://www.world-nuclear.org/info/inf27print.htm.