Resource Estimates for In Situ Leach Uranium Projects and Reporting Under the JORC Code

by A.D. McKay[1], P. Stoker[2], K.F. Bampton[3] & I.B. Lambert[4]

1. Introduction

The Uranium Industry Framework (UIF) was established in August 2005 by the Minister for Industry, Tourism and Resources, the Hon. Ian Macfarlane. The Steering Group comprised senior representatives of the uranium industry; the Commonwealth, South Australian and Northern Territory governments; and the Northern Land Council.

The report of the UIF Steering Group, was released by the Minister in November 2006 and made 20 recommendations to capitalise on opportunities for, and address impediments to, the development of Australia's uranium industry. In January 2007, the UIF Steering Group held its final meeting and Minister Macfarlane established the UIF Implementation Group, which considered how best to progress these recommendations.

This technical paper addresses Recommendation 4, which called for a paper and relevant supporting material to be prepared to, "provide information to ensure that the JORC Code[1] is properly understood and applied, and include case studies related to uranium mining, particularly in relation to in situ leach mining". This paper "should be developed for dissemination to uranium exploration and mining companies and presentation at suitable industry conferences." In considering the thrust of and responsibility for the various UIF recommendations, the Implementation Group allocated responsibility for coordination of the preparation of this uranium reserves and resources paper to Geoscience Australia, in consultation with the Joint Ore Reserves Committee (JORC).

Operation of the JORC Code

The JORC Code aims to ensure that **Public Reports*** on Exploration Results, Mineral Resources and Ore Reserves contain all the information which investors and their advisers would reasonably require for the purpose of making a balanced judgement regarding the results and estimates being reported. It is important to note that the term Public Reports takes a wide meaning. Public Reports include but are not limited to: company annual reports, quarterly reports and other reports to Australian and New Zealand Stock Exchanges, or as required by law. Importantly, the JORC Code also applies to other publicly released company information in the form of postings on company web sites and briefings for shareholders, stockbrokers and investment analysts. The Code may also apply to environmental statements; Information Memoranda; Expert Reports, and technical papers referring to Exploration Results, Mineral Resources or Ore Reserves. See Clause 5 of JORC Code.

The Code has been operating successfully for a number of decades and, together with its adoption in full by the Australian and New Zealand Stock Exchanges under their listing rules since 1989, has brought about substantially improved standards of public reporting by Australasian mining and exploration companies.

In particular, the provisions in the ASX Listing Rules require adherence to the JORC Code, which in Clause 8 requires the identification of the Competent Person who 'signs off' on resource and reserve disclosures. The company is required to obtain that person's consent to the use of the information provided for the report in the form in which it is issued. That gives a role of central and publicly visible responsibility to the reporting geologist or other mining professional. The JORC Code does not regulate the procedures used by Competent Persons to estimate and classify Mineral Resources and Ore Reserves, nor does it regulate companies' internal classification and/or reporting systems.

In Australia, regulatory responsibility for disclosure of Exploration Results, Mineral Resources and Ore Reserves arises not only in relation to the ASX Listing Rules but also in connection with the broader Corporations Law requirements for proper disclosure to be made to shareholders and investors in connection with fundraisings, takeovers and other corporate activities, and under the *Trade Practices Act 1974*. These laws do have regard to widely acknowledged industry codes such as the JORC Code. Further information is provided in the paper ***The Liability of Company Directors and Competent Persons for Resource/Reserve Disclosure,*** which outlines some of the situations in which directors and mining professionals may become exposed to legal liability at common law and under statute in connection with reporting on resources and reserves.

---

[1] The *Australasian Code for Reporting of Exploration Results, Mineral Resources and Ore Reserves* (2004 Edition), prepared by the Joint Ore Reserves Committee (JORC) of The Australasian Institute of Mining and Metallurgy, Australian Institute of Geoscientists and Minerals Council of Australia.

The JORC Code is principles-based, rather than a prescriptive Code. It sets out minimum standards, recommendations and guidelines on the classification and public reporting of **Exploration Results***[2], **Mineral Resources*** and **Ore Reserves*** in Australasia. This paper does not constitute a formal addition to the JORC Code – it presents suggestions on practices that are consistent with this Code.

1.1 The JORC Code and Uranium

As a matter of principle, the requirements for reporting on uranium properties under the JORC Code are the same as for other mineral commodities. However, there are a few issues that are particularly important for uranium which specifically need to be taken into account:

- Radiometric probes or hand held devices are commonly used in exploration and evaluation of mineralisation – these need to be appropriately calibrated and adequate correction factors applied;
- Uranium can be out of equilibrium with its daughter products, and the extent of disequilibrium needs to be quantified in estimating uranium grades by gamma-based methods; and
- 'Check assays' of representative samples are required.

The reliability of the probe measurements, the number and distribution of measurements, and the extent of check assaying will constrain the category of uranium Mineral Resources that can be reported. The units used to report grades and tonnages should be unambiguous.

This paper focuses on the estimation and reporting of Ore Reserves and Mineral Resources for sandstone type uranium deposits amenable to in situ leach (ISL)[3] mining. There has been some debate in recent years as to whether the JORC Code adequately covers the reporting of uranium resource estimates for ISL projects. These present a special case partly because of the limited experience in Australia in evaluating and operating ISL projects. Also the mineralised zones are not exposed for study during the evaluation or mining of the deposits, and it can be difficult to recover representative samples in friable mineralisation for chemical and physical measurements.

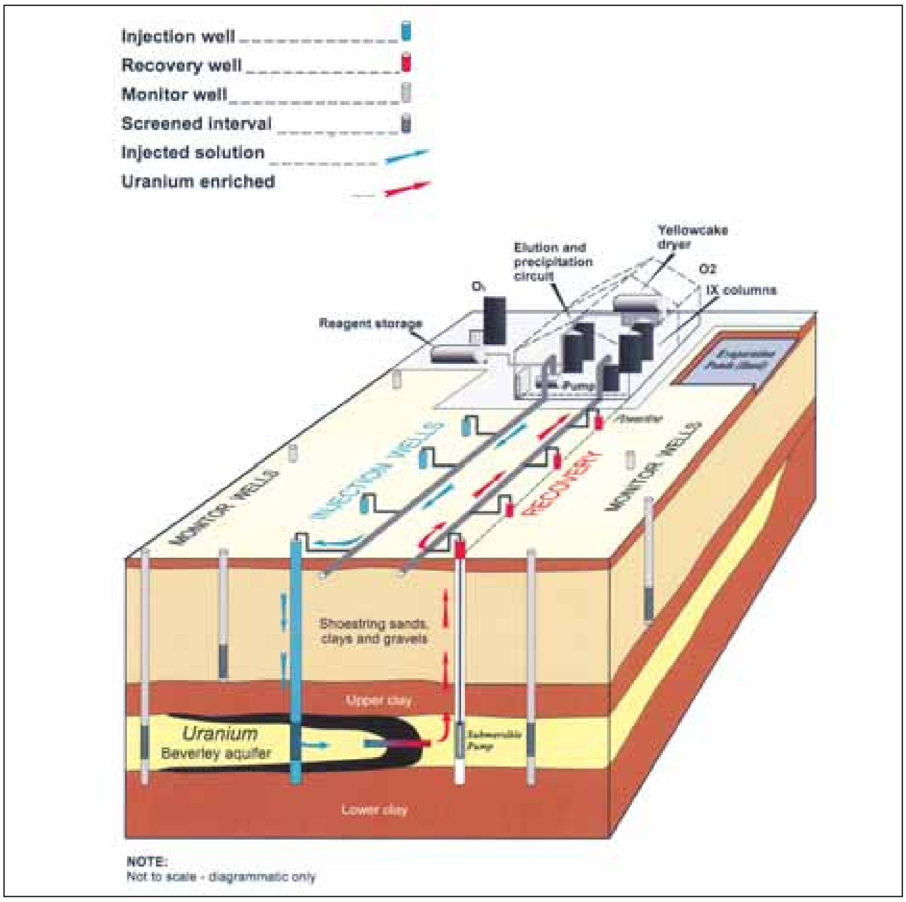

Fig. 1. Schematic of in situ leach uranium mine (Heathgate Resources, 1999)

The point is made that the JORC Code principles of transparency and materiality are met if information is provided on tonnage of resources, average grade, tonnes contained U_3O_8, and other resource estimation parameters. The third JORC Code principle of competence is met by the requirement that Ore Reserves and Mineral Resources must be estimated by a **Competent Person***. The Code specifies the qualifications and experience required of a Competent Person. The experience and knowledge of the Competent Person are critical in preparing estimates of ISL uranium resources and these include radiometric drillhole data, quality assurance/quality control (QA/QC) procedures for this uranium data, and hydrogeological features influencing the operation are important.

2. In Situ Leach Projects

Sandstone uranium deposits can have various forms, depending on whether they are in sheet sands or

---

[2] Terms defined in the JORC Code are emboldened and provided with an asterisk on their first mention. The defined terms are in ordinary text but with initial capitals as in the JORC Code on subsequent mention. Readers are referred to the Code's definitions of these terms. A copy of the Code is available at www.jorc.org.

[3] Also known as in situ recovery (ISR).

palaeochannels/valleys, and whether they are structurally controlled. They range from sinuous, laterally extensive roll fronts to tabular or irregular deposits. Where the mineralisation occurs **beneath the water table**, it can be evaluated for in situ leach mining.

ISL mining technology for uranium was developed independently in both the USSR and USA in the mid 1970s. The method was conceived for extracting uranium from typical roll-front type deposits located in water saturated permeable rocks that were not suitable for conventional mining techniques. Commercial ISL uranium mining began in the United States in the mid-1970s (Underhill, 1992) and subsequently this method was used for deposits in a number of eastern European and central Asian countries. Kazakhstan has had major ISL mines since the early 1990s. In Australia, ISL mining experience is limited to Beverley mine (South Australia), which commenced production in 2001. A second ISL mine is being developed at Honeymoon, also in South Australia.

Figure 1 illustrates the general features of an ISL operation. Site specific characteristics determine whether an acid or an alkali leaching solution is most effective. The leach solutions are pumped through the mineralised zone (porous, saturated sands) and a portion of the contained uranium is dissolved. The mineralisation is typically low grade – commonly below 0.2% U_3O_8 – and recoverability of the uranium by ISL is commonly 60-70%. The permeabilities of each of the sand units containing mineralisation are an important consideration. The uranium-bearing solutions are pumped to the surface where uranium is recovered by hydrometallurgical processing (ion exchange or solvent extraction).

The issues relating to the evaluation and reporting of uranium Mineral Resources in ISL projects in Australia are discussed in the following two sections, which deal with:

- uranium grade measurements; and
- estimating and reporting the uranium Mineral Resources.

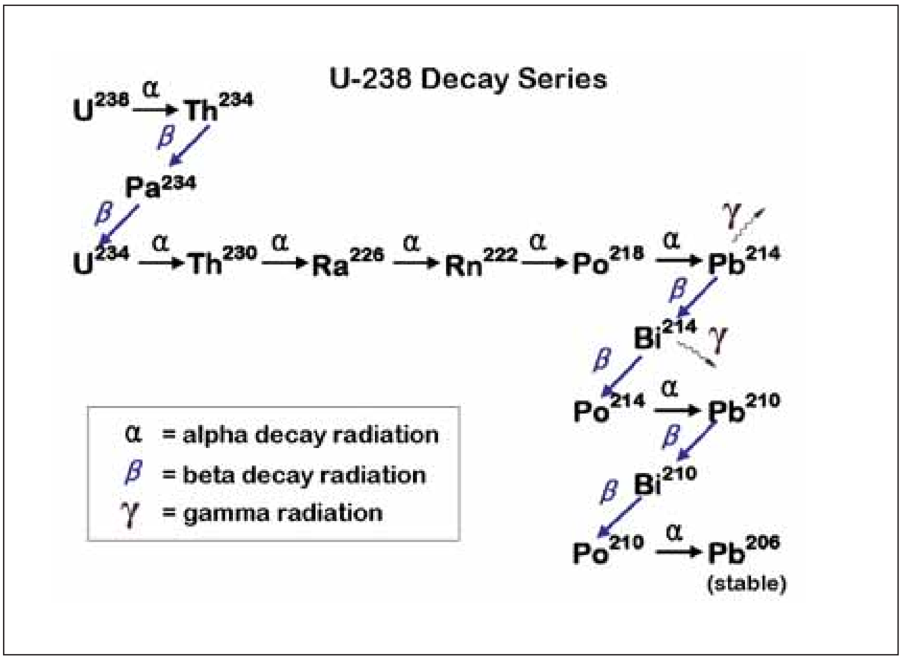

Fig. 2. U^{238} decay Series (Source: Argonne National Laboratory, 2005)

Australian and USA case studies are used to illustrate these issues.

3. Uranium grade measurements for ISL Projects

Radiometric data for evaluation of in situ leach uranium deposits are acquired by downhole logging techniques. These are:

- gamma ray logging which measures gamma radiation from radioactive daughter isotopes produced from isotopic decay of uranium-238 (U^{238}). Consequently, the uranium determination can be inaccurate due to the natural disequilibrium between uranium and its daughter isotopes; and
- prompt fission neutron (PFN) logging which provides a direct measure of uranium, these measurements are not affected by natural disequilibrium.

The continuous nature of the radiometric data from downhole probes provides a complete measure of uranium grades in the host sands whereas core recovery from conventional drilling would be poor or non-existent for these holes.

For modern down-hole logging equipment, the radiometric measurements are recorded electronically and can be displayed in a digital or graphical (analog) format, whereas for old downhole logging equipment (legacy data) measurements were only recorded graphically.

The Competent Person must prepare geological interpretations of the mineralised zones and enclosing sediments, and resource outlines for the sandstone hosted uranium deposit. This is a similar process to that used for resource estimates of other types of mineral deposits. Graphical representations of radiometric/electric logs are essential for interpretation of mineralisation in drillholes and for geological correlation between drillholes.

Downhole logging is used mostly in conjunction with open hole rotary mud drilling which is a relatively rapid, low cost drilling method. It may be difficult to obtain representative samples (core, rock chip) of unconsolidated sands and gravels which host the deposits by using conventional drilling methods such as reverse circulation. Rotary mud drilling is often used because it causes minimal disturbance of the soft unconsolidated sands, and mud coating of the walls keeps the hole open for sufficient time to complete logging with a downhole probe. However, with rotary mud drilling, there is severe lag of sample material and mixing across sample intervals. Consequently, chemical analyses of sample cuttings are usually not undertaken for grade determination because they are not normally representative of specific sample intervals. Electrical logging methods (resistivity and induction) are used down the hole to provide accurate information on lithologies.

3.1 Gamma ray logging

Gamma-ray probes are widely used to estimate uranium grades in drill holes, particularly those in sandstone-hosted uranium deposits. These probes measure gamma radiation emanating primarily from Bi^{214} and secondarily from Pb^{214}, produced by the radioactive decay of uranium (Fig. 2). Conversion factors are then applied to estimate the 'equivalent uranium' grades (eU_3O_8). Radiometric grades for mineralised intervals are determined by processing of either electronically recorded data files or from digitisation of graphical representations of older logs using techniques including 'half amplitude method', or 'deconvolution'[4].

3.1.1 Adjustment factors

The radiometric data from downhole gamma ray probes require adjustments to allow for a number of factors such as: the presence of casing in the hole, hole diameter, presence of water or air in the hole, logging speed, and probe characteristics (eg. dead-time[5] and measuring intervals). It is good practice to record the name and model number of the probes used and particulars of each hole on the drillhole logs. Each probe must be individually calibrated to correct the initial radiometric data - a K-Factor[6] is determined for each unit in order to standardize equivalent assays[7]. K-Factors can be determined from specially designed calibration pits. Comparison with assays from representative drill core samples where satisfactory recovery has been achieved is recommended for validation (QA/QC) of the radiometric grades, and repeat runs in a hole over time are useful for monitoring instrument drift.

However, comparison with representative core assays for **primary calibration** is not considered to be good practice because of:

a) the orders of magnitude difference in sample volume (probe measures gamma radiation emanating from spheres of influence up to 1 m diameter whereas drill cores are usually 8-10 cm. in diameter)
b) variability of grade in the interrogation volume in the natural environment
c) variability of disequilibrium in the interrogation volume in the natural environment

Calibration is best done in specially designed calibration pits and must be repeated at regular intervals. The South Australian government's Department of Water, Land and Biodiversity Conservation manages the Adelaide Model (AM) calibration test pits and related facilities in the Adelaide suburb of Frewville. These calibration facilities are available to companies on a commercial basis. If probes have been carefully calibrated and necessary correction factors applied to the results, then equivalent uranium grades measured with different logging units may be merged into a single database for resource estimations. The Adelaide pits are presently the only such facility in Australia, and there are similar installations in Ottawa Canada and Grand Junction, Colorado in the US.

Uranium grades measured by gamma ray probes should, where possible, be verified by drilling a number of cored drill holes. Grades determined by chemical analyses of the drill core can be compared with radiometric grades for corresponding intervals in the hole. An appropriate analytical technique must be used which will give uranium grades that can be compared with radiometric grades. The analytical technique to be used should be decided after discussions with the analytical laboratory. In addition, the drill core provides lithological information on the sedimentary sequence which can verify the down hole electrical measurements (resistivity and induction) for lithological logging. The Competent Person must decide on the validity of the corrected gamma ray assays results, taking account of the difficulties in obtaining representative samples from drilling and the larger sample volumes represented by the probe assays.

Representative core samples must also be taken throughout the deposit in order to measure the density of the host sands for tonnage estimation. All data must be clearly identified as to the source of the information (eg radiometric data vs chemical analyses, core drilling vs rotary mud drilling).

Holes are mostly logged from the bottom up to maintain optimum logging speed.

---

4 Technique for refining of downhole gamma ray data.

5 An interval of time (normally in microseconds) during which logging tool counts cannot be recorded due to transmission/recording 'bandwidth' for a particular logging setup – includes tool, cable (length sensitive) and up-hole system. Only significant at high count rates.

6 An experimentally determined tool-specific constant of proportionality relating (deadtime-corrected) gamma count rate to radiometric grade. Must be regularly monitored.

7 For detailed information: Estimation of Mineral Resources and Mineral Reserves Best Practice Guidelines 30 May 2003 - Adopted by CIM Council on 23 November 2003.

3.1.2 Disequilibrium

Radioactive isotopes lose energy by emitting radiation and transition to different isotopes in a 'decay series' or 'decay chain' until they eventually reach a stable non-radioactive state. Decay chain isotopes are referred to as 'daughters' of the 'parent' isotope. When all the decay products are maintained in close association with uranium-238 for the order of a million years, the daughter isotopes will be in equilibrium with the parent (Bampton, Haines & Randell, 2001).

However, disequilibrium occurs when one or more decay products are dispersed as a result of differences in solubility between uranium and its daughters, and/or escape of radon gas. Differential solution and re-precipitation of uranium and its daughter isotopes results in disequilibrium. Uranium deposits hosted by permeable sandstones (particularly roll-front type deposits) are often in disequilibrium because of groundwaters flowing through the mineralisation.

Knowledge of, and correction for, disequilibrium is important for deposits whose grade is measured by gamma-ray probes. Disequilibrium is considered **positive** when there is a higher proportion of uranium present compared to daughters. This is the case where decay products have been transported elsewhere or uranium has been added by, for example, secondary enrichment. Positive disequilibrium has a disequilibrium factor which is greater than 1. Disequilibrium is considered **negative** where daughters are accumulated and uranium is depleted. This so called 'negative' disequilibrium has a disequilibrium factor of less than one but not less than zero. In extreme cases, areas of high gamma radiation can be caused by radiation from daughter isotopes, with little or no uranium present ('ghost ore').

Disequilibrium is determined by comparing uranium grades measured by chemical analyses with the 'gamma-only' radiometric grade of the same samples measured in a laboratory. There are practical difficulties in comparing chemical analyses of uranium from drillhole samples with corresponding values from downhole gamma logging, because of the difference in sample size between drill core (average grades in core or chip samples) and radiometric probe measurements (gamma response from spheres of influence up to 1 m in diameter). Also, any probe calibration (and/or assay) error will be misinterpreted as disequilibrium.

Disequilibrium is normally spatially variable in sandstone-hosted deposits and a single deposit-wide adjustment factor is rarely, if ever, appropriate. For example, the 'nose' of a roll-front deposit would tend to have the highest disequilibrium factor and be highest in uranium (relative to its daughter isotopes), conversely, the tails of a roll-front would tend to have the lowest factor and be low in uranium (relative to its daughter isotopes). Multiple lithology-based correction factors (some up, some down) were applied in the resource estimates for Beverley (Heathgate Resources, 1998) and grade-based correction factors were used for Honeymoon deposit (Bampton, Haines & Randell, 2001).

For some deposits, disequilibrium has been estimated approximately by comparing gamma-ray probe results with PFN measurements of uranium grades from corresponding intervals in the hole. However, again there are significant sample volume differences and the practice is highly prone to calibration errors in either instrument being ascribed to disequilibrium.

3.2 Prompt fission neutron logging probes

PFN probes measure uranium grades directly by counting neutrons emanating from the fission of U^{235} in the ore. Hence, these measurements are not affected by disequilibrium in the ore. A description of PFN probe technology is provided in Mutz (2007). PFN probes are expensive and currently there are considerable delays in delivery from the sole commercial supplier in the US. Uranium One Australia Pty Limited and Heathgate Resources use PFN probes to measure uranium grades in drill holes for estimation of Mineral Resources. The sample volume referenced by the tool is a sphere of diameter approximately 0.5 m.

In addition to facilitating more reliable resource estimates, these probes could also be used to improve the uranium recoveries from ISL injection wells because the screens[8] for each well could be placed at the uranium-rich zones within each hole. This could eliminate the problem of placing screens in zones of low uranium (but high gamma emitting daughter products devoid of significant uranium). At Beverley mine, current practice is to use gamma probe results to place the screens because the PFN is not used in the larger diameter production holes due to:

- limited tool availability in competition with delineation and exploration drilling;
- dubious cost/benefit; and
- need for excessive extrapolation from smaller diameter calibration holes.

However these holes are commonly mid-way between delineation holes that have PFN results.

Dedicated calibration facilities (tanks) are preferred for the PFN tools, and these should contain mineralised sands and groundwaters from the actual uranium deposit being evaluated. Uranium One's calibration facility at the Honeymoon project comprises four buried 1000 litre polythene tanks containing acrylic tubes (Skidmore, 2006). The tanks are filled with a mixture of sand and groundwater from

[8] The screens used are designed to allow passage of leaching fluid into and out of the mineralised zones while the remainder of the hole is completely cased and sealed.

the aquifer. Pre-determined quantities of yellowcake were mixed into the sands to produce mineralisation with known average grades. The sand in the calibration facilities has a similar porosity and mineralogy to that in the natural mineralised zones. The water in the facilities has the same salinity and geochemistry as the host aquifer. In addition, the pits are designed to allow calibration for varying hole sizes.

Heathgate Resources has a similar facility under construction at its Beverley mine site. PFN tools have also been calibrated in the concrete Adelaide Model gamma calibration facility, using uranium assay values of the pit materials rather than radiometric grades.

4. Estimating and reporting Uranium mineral resources for ISL Projects

Estimation of uranium resources for ISL mining requires the consideration of physical and chemical parameters in addition to those that are generally considered in resource estimates for deposits to be mined by conventional methods (open cut, underground). These additional factors, which are required for the Competent Person to be confident that there are 'reasonable prospects for eventual economic extraction'[9], include:

- permeability of the mineralised horizon;
- hydrological confinement of the mineralised horizon; and
- amenability of the uranium minerals to dissolution by weak acid or alkaline solutions.

Without some information on the mineralogy and hydrology it is questionable whether the Competent Person can positively assert that the reasonable prospects for eventual economic extraction test for a Mineral Resource have been met.

There are two common ways of estimating resources for ISL uranium deposits: (i) tonnage and average grade methods and (ii) the grade-thickness contour method. These are described below. The estimates resulting from either method can be reported in compliance with the JORC Code.

4.1 Tonnage and average grade methods

The volume of resources is estimated using either block modelling, seam modelling or cross-sectional methods. This volume is multiplied by average bulk density of the mineralised sands to give the tonnage of resources. Grades can be assigned by one of a number of techniques including the traditional polygonal (assigning the grade on a nearest neighbour basis to the areas surrounding each drill hole), power of inverse distance, and geostatistics. The estimation procedures must consider a number of parameters including intercept cut-off grade, minimum mineralisation thickness, and maximum thickness of included waste. Where no minimum thickness of mineralised zones is applied, a minimum grade-thickness (GT) in conjunction with a lower cut-off grade should be used in the estimation for narrow zones of mineralisation. GT calculations are grade multiplied by true thickness (metres).

An example of acceptable practice using the tonnage and average grade method

In a news release issued 29 August, 2006, to Toronto Stock Exchange, SXR Uranium One Inc. announced new resource estimates for Honeymoon. The Honeymoon Mineral Resource report clearly meets the JORC Code requirement to provide information on quantity (tonnages) and quality (grade) of the resource. Note that rounding in compliance with the guidelines in the JORC Code may result in apparent computational inconsistencies.

The resource statement includes average GT figures for each sand layer – this was additional information determined from the results of the method of estimation, but while GT was used as an interval selection criterion, GT was not used as the estimation variable.

In total 236 holes were drilled into the deposit on a 40 m square pattern, using rotary-mud drilling techniques. The grades of mineralised intersections were measured with a PFN tool.

The resources were individually estimated for five laterally continuous sand packages, each of which has its own hydrogeological characteristics arising from different episodes of sedimentation. "The Corporation defined five continuous system-wide

Sand	Ore (tonnes)	Grade (% U_3O_8)	Tonnes U_3O_8	Thickness (metres)	GT (m%U_3O_8)
EBS-5	89,000	0.13	120	1.4	0.18
EBS-4	45,000	0.17	77	1.2	0.20
EBS-3	140,000	0.37	530	1.4	0.51
EBS-2	410,000	0.28	1100	1.7	0.47
EBS-1	530,000	0.20	1100	2.1	0.43
Total	**1,200,000**	**0.24**	**2900**	**1.7**	**0.42**

Honeymoon project – Indicated Mineral Resources

9 Clause 19 JORC Code.

Eyre Formation basal sand packages, EBS 1-5, based on electrical (focussed resistivity and induction) log correlation from the current drilling program. In all cases, primary intercept cut-off is a minimum 0.4 m at 0.03% U_3O_8 with maximum 1 m internal dilution. The primary intercept grade cut-off is 0.03% U_3O_8 in view of the fact that: (i) the prior 0.01% U_3O_8 cut-off was unrealistically low, and (ii) 0.025% U_3O_8 being the effective detection limit of the PFN tool (at this logging speed and accumulation interval) as confirmed by independent assessment." (SXR Uranium One, 2007).

The lithologies in all holes were logged by one geologist and a uniform dataset was compiled. QA/QC was carried out on the drillhole database. Detailed sedimentological studies were completed to define permeable layers within the sand sequences.

"The database was queried for intercepts meeting the intercept criteria of 0.4 m minimum thickness and 0.03% minimum U_3O_8 grade, with up to 1 m of internal dilution allowed, within each of the five continuous Eyre Formation basal sand packages. 178 holes have at least one qualifying intercept and, of these, 159 have an intercept with at least 0.05m% U_3O_8. Intercepts with less than 0.05m% GT are discarded, except that where there are no intercepts with at least 0.05m% U_3O_8, the highest GT intercept is retained for modelling purposes – but not included in any resource. Where there are two intervals with at least 0.05m% U_3O_8 in the same sand in the same hole, they are cumulated without intervening waste – 13 instances only. There are then 313 intercepts with at least 0.05m% U_3O_8, an average of two (potentially mineable sand packages at this cut-off) per hole." (SXR Uranium One, 2007).

The Competent Person classified the estimates as **Indicated Resources***.

4.2 Grade-thickness contour method

The GT method is commonly used in the United States of America for estimating ISL resources for uranium deposits, eg. Wyoming and Nebraska, where details are not reported publicly. However, there are no examples of an Australian deposit for which resource estimates (public reports) were produced using this method. GT methods are used by operating staff at the Beverley mine to facilitate well field planning and ISL operations. However, these figures are not reported – all public resource estimates for Beverley were prepared using traditional block modelling or seam modelling techniques.

Resource estimates for US deposits often simply state tonnes of contained U_3O_8 and average GT (Catchpole & Kirchner, 1992). As noted above, in addition to reporting the grade-thickness information and contained U_3O_8, the corresponding tonnages and grades must also be presented in order to be in accordance with the JORC Code.

Estimates using this method are based on GT values for each mineralised intersection in drillholes. The units for GT are metre-percent (m%). A minimum GT cut-off is applied to ISL resources in the same manner as a cut-off grade is applied for resources mined by conventional methods.

Acceptable practice for grade-thickness contour estimates

Contour maps of GT values are prepared using the drillhole data. For resource estimation, the various contoured areas of the deposit are assigned a GT value; alternatively, the GT value can be assigned to an area of influence surrounding each hole. This area depends on the drillhole spacing, and lateral continuity of the mineralisation.

When combined with the bulk density of the deposit, the parameters of **'GT and Area'** are equivalent to the concept of **'tonnage of resource'** in two dimensional estimation methods for conventional mining of narrow vein hard rock deposits. In these methods the accumulation (GT) is estimated in two dimensions and the thickness is independently estimated, the grade is back calculated, and the tonnage determined from the volume (thickness by area) and the bulk density.

As part of a company's public statements on uranium Mineral Resources, the documentation[10] prepared by the Competent Person must record information on: the area of the deposit, minimum GT (referred to as GT cut-off), average GT, bulk density of the mineralised zones, and tonnes contained U_3O_8. As well as reporting the grade-thickness information (equivalent to accumulation estimations in narrow vein gold deposits) resulting in contained U_3O_8 statements, the corresponding resource tonnages and average grades must also be presented[11]. In that way the public reports will be made in accordance with the JORC Code.

4.3 Recovery factors

Recovery factors for ISL projects are commonly quoted as a combination of the recovery of the in situ mineralisation to the leach fluid (equivalent to the mining recovery in an underground mining operation – the percentage of the resource which is delivered to the surface) and the recovery in the metallurgical plant[12]. Recoveries are reported as a percentage of the contained U_3O_8 and these are influenced by:

[10] Reference in the JORC Code to 'documentation' is to internal company documents prepared as a basis for, or to support, a Public Report.

[11] Clause 25 JORC Code, "Resources must not be reported in terms of contained metal or mineral content unless corresponding tonnages and grades are also presented".

[12] Metallurgical recoveries are not normally included in ore reserve modifying factors for conventional mining operations.

- uranium disequilibrium, (if eU_3O_8 is being used in the resource estimate);
- hydrological connectivity between adjacent wells;
- mineralogy (eg coffinite, davidite or other minerals containing uranium);
- leachability of uranium in the host sands units; and
- performance of recovery plant (ion exchange, solvent extraction).

The recovery can be estimated by detailed studies including:

- core drilling and detailed assays to compare with gamma ray probe results or PFN tool results;
- petrology studies;
- bench-scale laboratory testing of bulk samples; and
- pump testing of well field.

However, there is increased recognition that ISL **field leach trials** provide more reliable, large scale tests of recovery. In addition, these trials also provide important data on the hydrology and permeability of the sands which host mineralisation. These are important parameters for mineral resource estimates. Comprehensive field leach trials were carried out at Beverley and Honeymoon uranium deposits, and trials are due to commence at the Oban deposit (SA) in late 2007. Ion exchange technologies have been established to be most effective for Beverley and Oban, while solvent extraction hydro-metallurgy is to be used at Honeymoon.

For most ISL operations, overall uranium recovery factors are commonly of the order of 60-70%. Higher recovery factors have been reported for ISL operations in Kazakhstan. The reporting of these recoveries in Ore Reserve reports is necessary to provide all the material information required by interested parties to understand the public report and ensure that the estimate is presented in a transparent manner[13]. The reporting of recovery factors in mineral resource reports is encouraged as in these deposits, "information on estimated mineral processing recovery factors is very important"[14] and improves the understanding of the basis for the Competent Person's assessment that the deposit has reasonable prospects for eventual economic extraction.

For earlier resource estimates prepared in the 1970s and early 1980s, companies usually reported the mineral resource simply as tonnes of recoverable U_3O_8. This reporting occurred prior to the introduction of the JORC Code in 1989, and is not in accordance with the Code, which does not allow reporting of only contained metal/commodity.

For ISL operations, it is difficult to evaluate the depletion of resources and, consequently, remaining resources at a given point in time. This is because ISL recoveries are a composite of both mining (in situ leaching) and processing losses. While the processing losses can be independently estimated as tonnage into the plant vs production, the details of the local in situ extraction are more difficult to estimate. An approximation of remaining resources can be made by subtracting the year on year production from the initial resource estimates, but this takes no account of uneven in situ recovery which may influence the potential economic extraction of the remaining material and hence its continuing status as a resource.

4.4 Resource categories for ISL resource estimates

The Competent Person is required to classify the estimates according to the resource categories defined in the JORC Code. This process is equally applicable to estimates of ISL uranium resources as for any other type of deposit. The categories are assigned after considering a range of geological and hydrogeological aspects, drillhole spacing, method and accuracy by which the grades were determined (eg assays, gamma ray probes and/or PFN tools), and other factors.

The following general guidelines have been applied in classifying ISL uranium resource estimates in recent years:

1. Where grades are based solely on poorly calibrated historical gamma data, with no corrections for disequilibrium, the estimates, at best, may be classified as **Inferred Resources***. For the use of historical poorly calibrated gamma data alone there needs to be some control of the gamma data with some core holes (or at least chips) to confirm the mineralogy that is the source of the gamma signature.
2. Where historical data is supported by properly calibrated grade data (gamma and PFN), the estimates may be classified as Indicated Resources, subject to hole-spacing, geological continuity and disequilibrium considerations for gamma ray probe measurements.
3. Where the grade data are well calibrated PFN data, subject to demonstrated continuity, hydrological aspects of the sediments are adequately understood, estimates could in principle be classified as **Measured Resources***. However in practice, for the only Australian deposit that has been completely drilled by PFN tool, the Competent Person classified the estimated resources as Indicated Mineral Resources (refer Honeymoon estimate August 2006 as previously described).

[13] Clause 5 JORC Code.
[14] Clause 28 JORC Code

Only Indicated and Measured Mineral Resources may be converted to Probable and Proved Ore Reserves by application of dilution/recovery factors, subject to economic and legal considerations (the **Modifying Factors***[15]). Because recovery[16] factors are difficult to measure for ISL deposits, and are generally accepted to be low relative to recoveries from more traditional mining methods, it means that the Competent Person may not have sufficient confidence in the modifying factors to convert these resources to Ore Reserves. However, after an ISL mine has been operating for several years or as a result of an ISL field leach trial it may be possible to estimate an apparent recovery factor by comparing production with resources, and apply this information to convert the remaining resources to Ore Reserves.

Mining companies often finance the development of new mines by borrowing capital from the banks. To qualify for loans, banks generally require some or all of the Ore Reserves to be in the Proved category. Junior companies seeking to develop new ISL mining projects may find it difficult to obtain finance if they have Indicated Mineral Resources and are unable to upgrade these to Measured Mineral Resources, or convert these resources to Ore Reserves.

5. Summary and conclusions

This paper presents suggestions on practices, which are consistent with this Code, for the estimation and reporting of Ore Reserves and Mineral Resources for sandstone type uranium deposits amenable to in situ leach mining.

Uranium grades are frequently estimated by probes, but uranium grades for reportable resources need to meet the same standard of verification as for other metals.

Sandstone type mineralisation that is below the water table can be considered for ISL mining. The uranium grade of each of the mineralised zones usually varies independently of the vertical thickness of the zone. GT, the accumulation of the vertical thickness and grade, is an 'additive variable' for statistical processing and can be used for two dimensional estimation, using either traditional or geostatistical methods as considered appropriate by the Competent Person.

The JORC Code principles (of materiality, transparency and competence) are met if information is provided on tonnage of resources, average grade, tonnes contained U_3O_8, and other resource estimation parameters including the area of the deposit, average GT, bulk density of the mineralised zones, and minimum GT (GT cut-off).

The Competent Person has the responsibility to document all parameters that were used for the resource estimation as well as any limitations on the database used. This information must be included in a public report based on the Competent Person's documentation if it is material to the understanding of the Public Report. This will comply with the transparency and materiality principles of the JORC Code.

Estimates for ISL resources are generally only classified as either Inferred or Indicated Mineral Resources. For those deposits where ISL has operated for some years and the recovery factors have been determined, it may be possible for the Competent Person to classify the estimates as Measured Mineral Resources.

Without recovery data derived from an ISL operation or a field leach trial it is unlikely that the Competent Person will have sufficient confidence in the modifying factors to convert Mineral Resources to Ore Reserves. While, in the absence of production information for the deposit being evaluated, recoveries can be estimated on the basis of detailed studies that do not necessarily include ISL field leach trials, confidence in the recoveries, and therefore in the conversion from resources to reserves, is greatly enhanced if an ISL field leach trial has been undertaken.

6. Acknowledgements

This paper has been developed with expert inputs from Jerome Randabel (Uranium Equities Ltd.), Colin Skidmore (Uranium One Australia Pty Ltd.) and Mark Randell (Curnamona Energy). Constructive comments on drafts of this paper were received from Peter Morris (MCA), Pat Stephenson (AMC Consultants Pty Ltd.).

7. Disclaimer

While the second author is Chairman of the Joint Ore Reserves Committee (JORC) the views expressed herein are personal and should not be taken as necessarily representing the position of JORC.

8. References

Argonne National laboratory, 2005: Human Health Fact Sheet. www.ead.anl.gov/pub/doc/natural-decay-series.pdf

Bampton, K.F., Haines, J.B. & Randell, M.H., 2001: Geology of the Honeymoon uranium project. The AusIMM Proceedings, Vol 306, No 2, The Australasian Institute of Mining & Metallurgy, p17-27.

Catchpole, G., & Kirchner, G., 1992: The Crow Butte ISL project – A case history. In *Uranium in situ leaching*, Proceedings of International Atomic Energy Agency technical meeting, Vienna, Oct. 1992, p. 81-94.

[15] Clause 11 JORC Code.

[16] Recovery here refers to the recovery of the uranium by the in situ solution rather than the traditional mining recovery, but the concepts are similar.

CIM, 2003: Estimation of mineral resources and mineral reserves best practice guidelines -prepared by the Canadian Institute of Mining and Metallurgy and Petroleum (CIM) led Estimation Best Practices Committee.

Curnamona Energy, 2007: Assessing an ISL Property. www.curnamona-energy.com.au

Dickson, B.L., and Fisher, N.I., 1980: Radiometric disequilibrium analysis of the carnotite uranium deposit at Yeelirrie, Western Australia. Proceedings of the Australasian Institute of Mining & Metallurgy No 273:13-19.

Heathgate Resources, 1998: Beverley Uranium Mine Environmental Impact Statement. June 1998.

JORC, 2004: The JORC Code 2004 Edition. Australasian Code for Reporting of Exploration Results, Mineral Resources and Ore Reserves prepared by the Joint Ore Reserves Committee of The Australasian Institute of Mining and Metallurgy, Australian Institute of Geoscientists and Minerals Council of Australia.

Mutz, P.R., 2007: Utilisation of Prompt fission neutron technology in greenfields uranium exploration. Australian Uranium Conference, Darwin may 2007. Australasian Institute of Mining & Metallurgy.

Skidmore, C.P., 2006: Honeymoon Uranium Project 'Australia's Fourth Uranium Mine' Australia's Uranium Conference, Adelaide July 2006. The Australasian Institute of Mining & Metallurgy.

Southern Cross Resources Inc., 2002: Annual Information Form 2001. Released to Toronto Stock Exchange.

SXR Uranium One Inc., 2006: Resource estimates for Honeymoon deposit, News Release 29 August 2006. SXR Uranium One Inc. announcement to Toronto Stock Exchange.

SXR Uranium One Inc., 2007: Annual Information Form 2006. Released to Toronto Stock Exchange.

Underhill, D.H., 1992: In situ leach uranium mining in the United States of America: past, present and future. In *Uranium in situ leaching*, Proceedings of International Atomic Energy Agency technical meeting, Vienna, Oct. 1992. ■

---

1. *Project Leader, Onshore Energy & Minerals Division, Geoscience Australia, FAusIMM*
2. *Principal Geologist, AMC Consultants Pty. Ltd., FAusIMM*
3. *Principal, Ore Reserve Evaluation Services, MAusIMM*
4. *Group Leader, Onshore Energy & Minerals Division, Geoscience Australia, MAusIMM*