BNL-105931-2014-CP

IMPROVING PROCESS CONTROLS AT IN-SITU LEACHING URANIUM MINES

Natalya Bokovoya[1], Biays Bowerman[2], Michael Browne[3], Colin Carroll[2], Sean Dunlop[4], A.Kasabekov[1], Karen Miller[3], Scott Purvis[5], Gulnara Yeligbayeva[6]

[1] NAC Kazatomprom JSC
Astana, Kazakhstan
[2] Brookhaven National Laboratory
Upton, NY USA
[3]Los Alamos National Laboratory
Los Alamos, NM, USA
[4]Mele Associates
Washington, DC USA
[5]U.S. Department of Energy
National Nuclear Security Administration
Washington, DC USA
[6]Kazakhstan Atomic Energy Committee
Astana, Kazakhstan 010000

Nonproliferation and National Security Department

Brookhaven National Laboratory

U.S. Department of Energy
National Nuclear Security Administration

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ABSTRACT

The U.S. Department of Energy's National Nuclear Security Administration (NNSA), the Kazakhstan Atomic Energy Committee (KAEC), and Kazatomprom are cooperating in an effort to improve process controls at in-situ leaching uranium mines. Historically nuclear material at uranium mines was not subject to detailed accounting and control procedures under IAEA Safeguards Agreements. Consequently Kazakhstan's State regulations on nuclear material accounting and control did not apply to natural uranium mining and concentration facilities. Kazatomprom recently instituted new corporate requirements for nuclear material accounting and control at its mines. Kazatomprom has initiated a plan to strengthen these requirements and to implement improved procedures for accounting and control in support of this effort. NNSA, KAEC, and Kazatomprom are cooperating on a study to assess new approaches for strengthening process controls at in-situ uranium mines. The results of this study could improve the timeliness and quality of the data that is used in the uranium accounting systems. The US/Kazakh team will evaluate systems involving commercial off-the-shelf (COTS) equipment that could provide real-time accounting of uranium as it is extracted from each wellhead and perform a mass balance on the entire process automatically. The process would cover pumping the pregnant solution for individual wells, through resin exchange, precipitation, filter-pressing and finally placing the yellowcake in drums for shipment. The study will be conducted at two Kazakhstani uranium mines: Appak and Zarechnoye. This paper addresses the initial efforts to define the scope of the program and the technical approaches to developing user requirements.

PART I

INTRODUCTION

This paper describes the activities planned for implementation between the U.S. Department of Energy National Nuclear Security Administration (DOE/NNSA), the Kazakhstan Atomic Energy Commission (KAEC) of the Ministry of the Industry and New Technologies (MINT), and National Atomic Company (NAC) Kazatomprom JSC for improving materials management and inventory control practices for natural uranium at uranium mines. The project was developed after a 2010 expression of interest by Kazakhstan to strengthen its accounting and control processes at its uranium mines. Kazakhstan invited the National Nuclear Security Administration (NNSA) to participate in a pilot program with the International Atomic Energy Agency (IAEA).

At the time, there was a growing interest internationally in strengthening the security of uranium ore concentrate and in fact, the IAEA was considering moving the starting point of safeguards forward. NNSA saw the opportunity to work with Kazakhstan to improve process controls and security of uranium ore concentrate and possibly to contribute to any future safeguards initiative by the IAEA.

NNSA was also interested in working with Kazakhstan because it is a strong supporter of the nonproliferation regime; it gave up its nuclear weapons in the 1990s after declaring independence from the Soviet Union, and it is a huge uranium producer. Its two mines, Appak and Zarechnoye, have state-of-the-art accounting and control systems and a well–qualified operations and engineering staff.
As a consistent supporter of nuclear nonproliferation, Kazakhstan signed the following international agreements:

1. Treaty on the Nonproliferation of Nuclear Weapons (Resolution of the Supreme Council of the Republic of Kazakhstan No.2593-XII dated December 13, 1993, "On the Accession to Treaty on the Nonproliferation of Nuclear Weapons")
2. Agreement between the Republic of Kazakhstan and the International Atomic Energy Agency on Application of Safeguards in Connection with the Treaty on Nonproliferation of Nuclear Weapons (The Agreement has been ratified by the Republic of Kazakhstan in accordance with the Presidential Decree of the Republic of Kazakhstan No. №2344 dated June 19, 1995)
3. Protocol Additional to the Agreement between the Republic of Kazakhstan and the International Atomic Energy Agency on Application of Safeguards in Connection with the Treaty on Nonproliferation of Nuclear Weapons (Vienna, February 6, 2004) (Ratified by Law of the Republic of Kazakhstan №229-III dated February 19, 2007).

Kazakhstan is the world's largest producer of natural uranium, and it has the world's second largest explored uranium reserves and resources. Table 1 compares Kazakhstan uranium production in 2013 to the next nearest regional producers, Africa and Canada. Together, these regions produced about 71% of the total global uranium production. Also shown in Table 1 are 2013 figures for the companies that operated the uranium mines, Kazatomprom, Cameco and AREVA, and who account for about 53% of the total uranium production in the world.

Table 1. Comparative 2013 World Production Values for Uranium

Production Source	**Tonnes Uranium**	**Percent of Global**
Region or country		
Global	58,827	100
Kazakhstan (country)	22,000	38.3
Africa	9,706	16.5
Canada	9,353	15.9
Mining production organization		
Kazatomprom	12,500	21.4
AREVA	9,331	15.9
Cameco	9,076	15.4

Since becoming the leader in uranium mining in 2009, Kazakhstan, is the main supplier of natural uranium for peaceful nuclear energy and is known as a consistent supporter of nuclear nonproliferation and "peaceful atom" principles. Consistent with these principles, Kazakhstan is willing to share information about its current practices in natural uranium accounting and control.

A joint Kazakh and U.S. work team has been assembled to review the existing natural uranium process control and accounting systems at the two Kazakh sites, Appak LLP and JV Zarechnoye JSC, and to compile specific recommendations for their improvement. The team will then develop a system of process control improvement recommendations which establishes process control system performance capabilities, conditions of operation, and operational and budgetary constraints. These recommendations will be documented following the format of a User Requirements Document.

The first part of the work will be to gather specific information on the operating process control and accounting systems used at the two mines. The questions are, can process controls at uranium mines be strengthened from today's state-of-the-art systems? Is near real time uranium monitoring in the well field achievable? How can human errors be reduced in the process control systems?

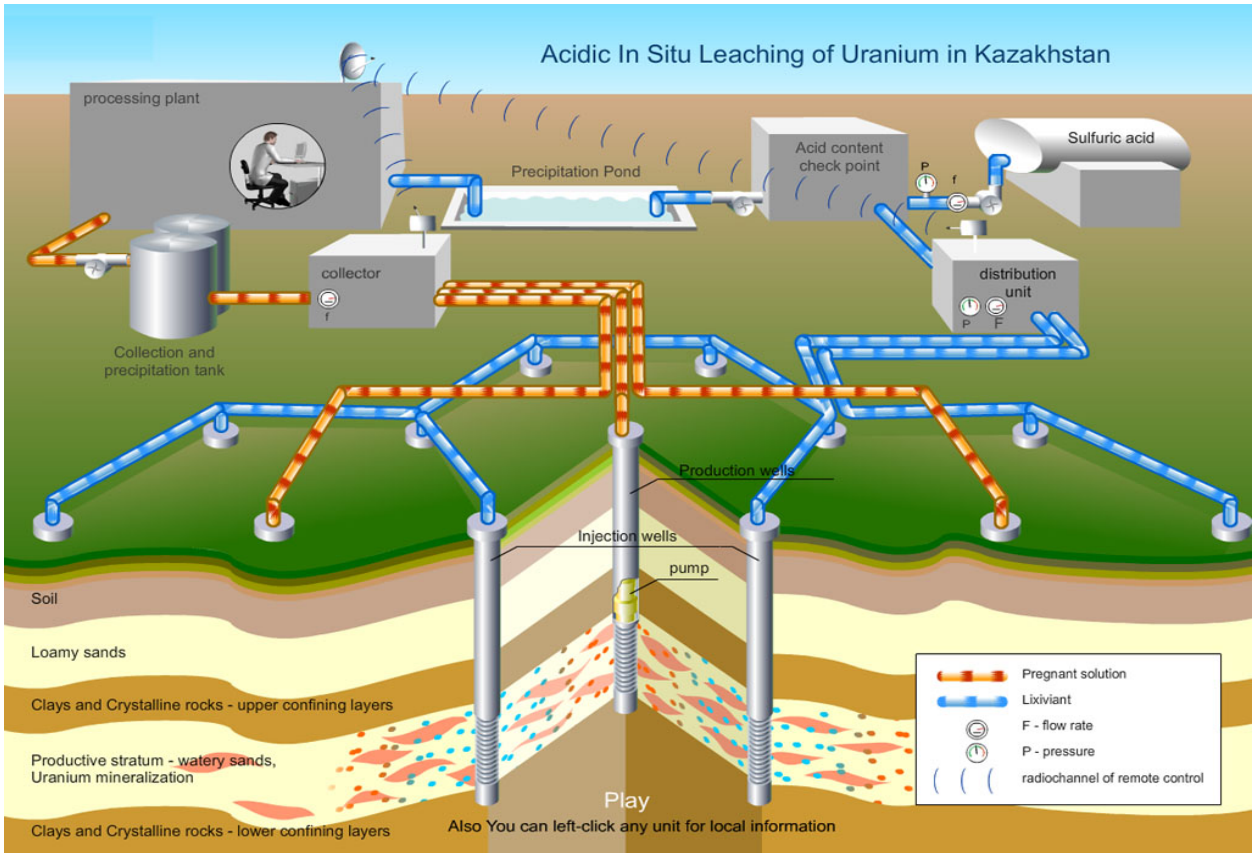
From this, a list of best practices will be compiled and included in the Document (Recommendations Document). The Recommendations Document will conform to a User Requirements Document format as used in the software development industry; thereby allowing users and other stakeholders to specify their product needs just as software users specify their needs to software development engineers. The User Requirements specified may also be ranked on a scale from mandatory to desirable to optional. Similarly, the best practices identified in the Recommendations Document in this task may fit in a mandatory category based on legal requirements in a country, or they may fall into desirable or optional categories due to financial or engineering considerations. Some best practices may be instituted immediately with minimal engineering and equipment changes, while others may require some investment in mine or uranium processing plant infrastructure modifications.

After the requirements document is complete high level designs of the improved system may be developed and evaluated for cost effectiveness.

Efforts to date include assembling a joint team of appropriate experts and literature searches and information exchanges on uranium mining and processing plant controls and accounting. The U.S. team includes a uranium mining engineer, a chemical process engineer, and a radiation instrumentation expert. The Kazakhstan team includes the engineers and specialists responsible for natural uranium accounting and control from the Appak and Zarechnoye mining sites. Visits to the mining sites are scheduled for early October to begin to develop the technical information on which to base the Recommendations document.

Process Controls at uranium mines in Kazakhstan

Uranium mines in Kazakhstan use the in-situ leaching (ISL) process in which an acid solution is injected into the ore body to dissolve uranium minerals selectively. A schematic flow diagram for the mine extraction process is shown in Figure 1. The acid solution is pumped out of the geological formation with hundreds of extraction wells situated downstream of the acid solution flow. The chemical make-up of the acid solution is carefully controlled. Flows into and out of the ore body are monitored to assure that total net volumes injected are approximately equal to or slightly less than total liquid volumes extracted. There can be as many as six injection wells for each extraction well. This process works best in uranium bearing sandstone formations, which occur in many locations around the world. The ISL technology (also referred to as in situ recovery or ISR) has displaced traditional rock ore mining for uranium.



A more detailed breakdown of the process flow is shown in the block diagram in Figure 2. Extraction and processing steps from the wells through a typical processing plant are illustrated, and block letters indicate typical locations for monitoring or sample retrieval. These typical monitoring or sampling points are explained in Table 1. The Recommendations Document to be prepared will be more rigorous and complete as more process details are obtained from the Appak and Zarechnoye mine sites.

Pregnant solutions containing dissolved uranium are extracted from the wells by pumps; and downstream pipes combine wellhead flows to collect at the Solution Collection and Distribution Unit (SCDU) (See Figure 3). The extracted pregnant solutions are monitored in the SCDU for

each wellhead by flow rate monitors (monitoring points **A** and **B** in Figure 1). The readings are recorded at least 1 time per shift (2 times a day). To measure the uranium content from individual extraction wells, fluid samples are taken through sampling devices according to the sampling map. The samplers are installed at each wellhead and in the SCDU; after collection, the samples are analyzed in an on-site physical-chemistry laboratory. The analysis results are used to quantify uranium extracted from the wellheads by multiplying the extracted volume of pregnant solutions by uranium content in these solutions.

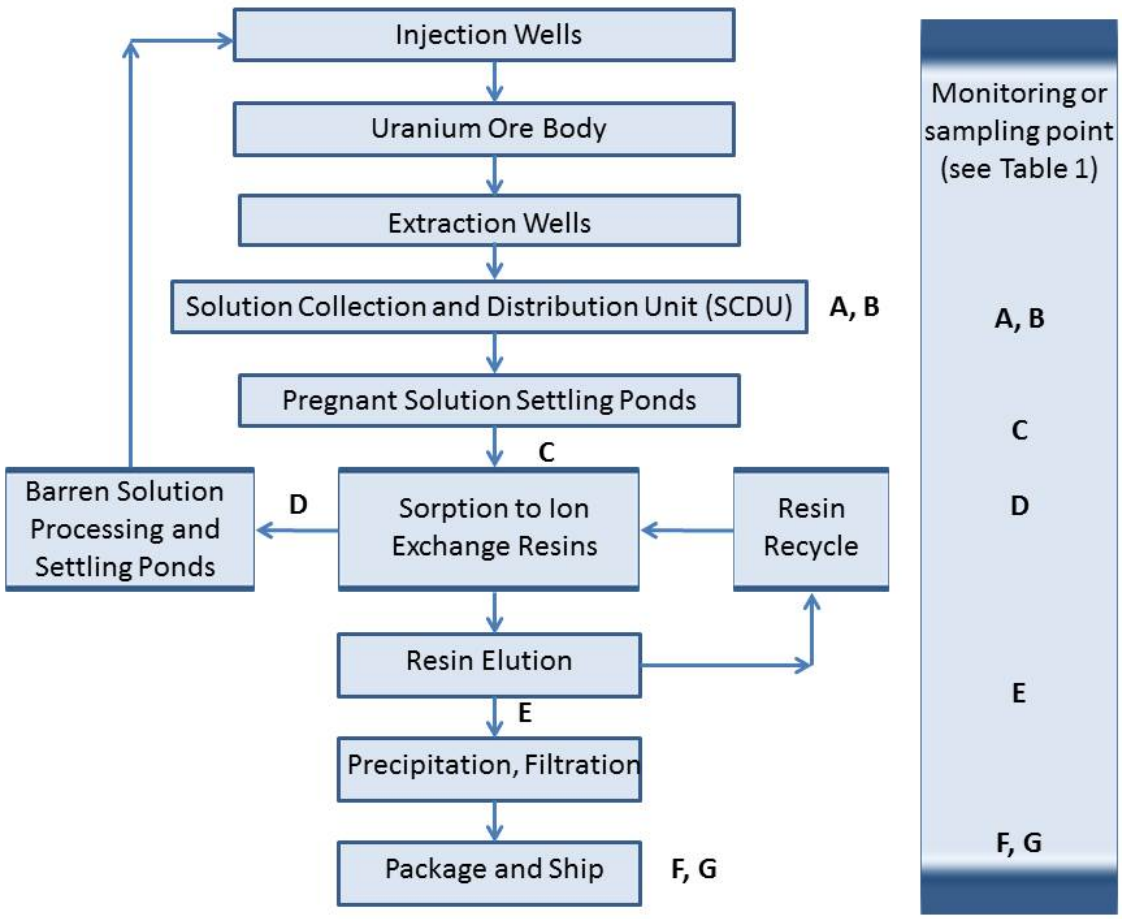


Figure 2. Block Diagram Representing Process Flow at the Mine and Processing Plant [1]

A flow measurement device (not shown) is installed at an SCDU; it represents a continuous consolidated measure of the mining operation in the extraction wells? What does the preceding mean? Process monitoring and accounting is implemented and the operating information is generated at each uranium mine as described next.

Table 1. Examples of Monitoring and Sampling Locations

Process Step	**Quantity (units)**	**Relevance - comment**
A - Extraction wellhead	Flow (L/s)	Process control - determine uniform wellhead flow
B - Pregnant solution	U concentration	Mass balance – initial quantity of

sample (taken from wellhead at A)	(mg/L)	U from ore body
C – Combined flow into process plant, and pregnant solution uranium content	Flow (L/s) U concentration (mg/L)	Process control - input flow into process plant Mass balance
D - Barren solution sample	U concentration (mg/L)	Mass balance – quantity of U not extracted from pregnant solution
E - Ion exchange resin elute sample	U concentration (g/L)	Mass balance – quantity of U to be made into UOC for shipment
F - Uranium ore concentrated solids	U concentration (%) Water (%)	Mass balance – quantity of UOC to be shipped to processing plant
G - Radiation measurement	Uranium per package (kg)	Rapid verification of total quantity of uranium

Figure 3. Mine worker checking flow measurements in a Solution Collection and Distribution Unit (SCDU)

After the SCDU units, the extracted pregnant solutions are supplied to the precipitation pond via the collection headers, and then to the processing plant. Flow measurements to determine the liquid volumes received for processing (monitor point **C** in figure 1) are installed at pipelines supplying pregnant solutions. For measurements of uranium content of the received pregnant solutions, a solutions accumulator (dropper) is installed receiving the pregnant solutions for processing over a shift. At each shift end, the samples are taken from the dropper and are analyzed in on-site. The analysis results are used to quantify the uranium mass in the flows being sent for processing by multiplying the volume of pregnant solutions delivered for sorption processing by uranium content in these solutions.

Uranium is recovered from pregnant solutions through steps of sorption on ion exchange resins, stripping from the resins, precipitation, filtration, finally heat treatment-for drying. The process

control keeps accounting for uranium quantity in leaching solutions, which are recovered in the sorption step and returned to the wellfield (process point **D** in Figure 1), and for uranium mass in the recycled solutions, which remain within the processing plant. To account for leaching and recycled solutions, flow monitors and samplers are installed in the respective headers.

Uranium mass balance is an important measure of process efficiency as well as a parameter of interest for safeguard principles. Uranium mass measurements of the pregnant solution (**B**) provide a measure of the continuing efficiency of the injection well system and the remaining uranium content in the portion of the sandstone formation undergoing leaching. Mass measurements of uranium in the barren solution (**D**) compared against **C** reveal how well the ion exchange resins are removing uranium from the pregnant solution. Quantities of uranium in **D** should be very low to non-detectable, because this stream is re-injected into the ore body.

Uranium measurements of the solution stripped from the ion exchange resins (**E**) provide an estimate for the final product mass. When **E** is compared to **D,** losses due to uranium entrained on the ion-exchange resins can be quantified.

Depending on the facility design, the processing plant may produce yellowcake (Figure 4) or U_3O_8, (uranium ore concentrate, Figure 5). One of the last points for a uranium mass measurement is after packaging (**F**) for shipment. Each packed container is sampled and weighed, then tagged, specifying its weight data, production date and serial number. Each packed container is sealed. Weight data and the production date for each container are recorded in accounting documents at the same time as applying the tag containing the same information. The uranium mass in the final product is characterized based on final product uranium content analyses, and then its compliance with the quality standards is verified.

Figure 4. Yellowcake product

Figure 5. Uranium ore concentrate (U_3O_8)

Chemical methods for determining uranium content may involve traditional wet chemical analytical methods, e.g., the Davies-Grey titration method, or more recently developed instrumentation techniques such as inductively coupled plasma mass spectrometry (ICP-MS). Packages shipped from all Kazakhstan mines are characterized based on sample analyses conducted at a central certified Kazatomprom analytical facility. The specific chemical tests

used for process control or uranium mass determinations will be an important consideration for recommended practices in the Recommendations Document. In addition, systems for assuring representative sampling and meeting quality assurance standards must be integrated into the recommended practices, as these contribute to confidence in quantities of uranium production reported to international regulatory bodies.

Some preliminary analysis has been conducted to determine if radiation detection instrumentation for gamma and neutrons can be used to determine the uranium mass (**G**). This is not a standard method in uranium mining. However, it is a convenient non-destructive analytical technique used in other uranium processing facilities. As a method with the potential for use in continuous real-time process monitoring, it is also being evaluated for improving uranium inventory control at various monitoring points in the processing plant. A literature review and preliminary modelling calculations show that radiation detection techniques will not work at wellhead locations under active pipe flow. This is due to the low uranium concentrations present. Gross gamma detection methods are not effective for giving quantitative data. However, neutron detection may work at various process stages and a field evaluation is proposed to obtain neutron measurements at the mines of both concentrates and products.

This completes the description of the uranium process accounting system within each mine. In Kazakhstan, each uranium mining facility calculates a uranium material balance on a monthly basis. To accomplish this calculation, the processing plant operation is stopped and the operators measure the uranium holdup in the process equipment according to the layout of the process equipment. Material balance is calculated using the data on the uranium quantity supplied for processing, the uranium quantity in the final product, and the uranium quantity in holdup.

To provide further assurance in processing operations and material balance calculations, each uranium mining facility has material security measures in place. A system of physical protection measures is implemented in the mine area including access control and video surveillance.

Currently, the uranium mines and processing plants of "NAC" Kazatomprom" JSC use a natural uranium accounting and control system designed and built in-house, which is based on the principles of:

1. Administrative allocation of duties, authorities and responsibilities for compliance with requirements of the natural uranium accounting and control system at the facility level;
2. Available system of technical and organizational arrangements focused on identification and assurance of natural uranium inventory.

The objective of the natural uranium accounting and control system (NUAC) is to quantify the inventory, identify condition and location of the natural uranium and assist in detecting the potential losses.

One of the options to be considered for improving the current accounting system is the use of an automated system for process accounting and control of uranium to reduce human error. As an example, flow measurement data could be delivered directly into an electronic database, thus reducing the risk of inaccuracies in the initial data due to human transcription errors.

CONCLUSIONS

The final "product" will be the Process Accounting and Control System Improvement Recommendations or Recommendations Document, which will provide a framework for natural uranium accounting and control in mining and uranium processing facilities that may be useful worldwide.

The next steps are to draft the User Requirements or a system of process control improvement recommendations. Second, additional information exchanges are planned in August and September to evaluate various technical approaches and develop test plans. Then the team will conduct site visits to the Appak and Zarechnoye mines in early October. Finally, the high level designs will be drawn up for process control improvements and evaluated for cost and effectiveness.

REFERENCES

1. International Atomic Energy Agency, "Manual of Acid In Situ Leach Uranium Mining Technology," IAEA-TECDOC-1239 (2001)
2. World Nuclear Association, "In Situ Leach (ISL) Mining of Uranium", http://www.world-nuclear.org/info/Nuclear-Fuel-Cycle/Mining-of-Uranium/In-Situ-Leach-Mining-of-Uranium/
3. Roscoe Postle Associates, Inc., for Uranium One, Inc., "Technical Report on the Zarechnoye Uranium Mine, Kazakhstan," NI 43-101 Report, (2012).