Attachment 1

Cameco Uranium Material Description, Process Histories, and Analytical Data
Fuel Services Brochure from Cameco

Blind River Flow Diagram

Process Flow for Calcined Product, Description of Fluoride Product
Blind River Refinery

Port Hope Conversion Facility
CAMECO CORPORATION

Cameco Corporation, with its head office in Saskatoon, Saskatchewan, is the world’s largest publicly traded uranium company. It has uranium mining operations in Saskatchewan and the USA, and uranium processing facilities in Ontario. Cameco’s uranium products are used to generate electricity in nuclear power plants around the world, providing one of the cleanest sources of energy available today. Cameco sells uranium concentrates (U₃O₈), from its mines as well as services to refine and convert concentrates to uranium dioxide (UO₂) and uranium hexafluoride (UF₆). The UO₂ is used in heavy water CANDU reactors while UF₆ is an intermediate product in the fuel cycle of most commercial reactors. Cameco sells these products and services to electric utility companies worldwide which, in turn, also contract with other suppliers within the nuclear fuel cycle to obtain their required type of reactor fuel.

The Fuel Services Division of Cameco Corporation refines and converts uranium for use in the manufacture of reactor fuel for electric utilities. Uranium processed by the Fuel Services Division each year contains more energy than Canada’s total annual oil production. The information in this brochure describes how Cameco’s facilities at Blind River and Port Hope, Ontario, refine and convert uranium to reactor fuel or other intermediate products.

Uranium concentrates from around the world are received at the Blind River refinery, where they are purified to produce a nuclear grade uranium trioxide (U₃O₈). This product is shipped by truck to Port Hope for conversion to UF₆ for ultimate use in light-water reactors or to UO₂ for use in CANDU heavy-water reactors, or as a blanket fuel in Pressure Water Reactor (PWR) or Boiling Water Reactor (BWR) types of light-water reactors.

Since entering the international conversion market in 1970, Cameco has processed uranium ore concentrates from virtually every major producer and has supplied processing services to more than 75 utilities in 15 countries. Since 1958 the company has also produced uranium dioxide fuel for all of the CANDU reactors operating in Canada.
THE URANIUM FUEL CYCLE

Original Port Hope plant, 1932

UF₆ plant -- Port Hope
The number of known metals has been increased by one... a new element which I see as a strange kind of half-metal. I propose to call this new element Uranium”. Martin H. Klaproth, announced the discovery of uranium on 24 September 1789. He named the new element after the recently discovered planet Uranus.

Throughout the 1800s this new element was used only to provide colour for glassware and ceramics. Uranium's radioactivity was first observed in 1896 by Henri Becquerel. Several years later the Curies discovered radium, which is formed from the decay of uranium. It is an intensely radioactive element which emits light and heat. The remarkable properties of radium and its use for radiation treatment for cancer and other applications led to a rapid expansion in the mining of uranium ore in the early 1900s. The demand for uranium itself was still very small, and most of it was discarded as a waste product after the radium had been extracted.

A series of scientific breakthroughs over the next 40 years led to the 1939 discovery of nuclear fission and uranium was the basis for this reaction. Initial interest was for military applications but after the Second World War ended, attention was turned to developing peaceful uses for this energy. In 1951, the first electricity was generated from this fission process. It lit four ordinary light bulbs at a research centre in the USA. This was the birth of today's international nuclear power industry.

Uranium is present in low concentrations in many rocks and in the seas, but its extraction is only economically viable from ore deposits. It is more plentiful than “common” elements such as silver or mercury. In 1931, prospector Gilbert Labine discovered Canada's first uranium deposit at Great Bear Lake in the Northwest Territories. This was the birth of Eldorado, one of Cameco's predecessor companies.

Uranium mining takes place in both open pit and underground mines. The techniques used are similar to any metal-mining process, with blasting followed by ore collection and crushing. In some cases, extraction of uranium from ore deposits can take place by dissolving it from the surrounding permeable rock formation in a liquid pumped through bore-holes. This process is called in situ leaching (ISL).

Run of mine ore is taken to a mill, where it is finely ground, leached from the gangue materials with acid, purified, filtered, and dried or calcined. The resulting uranium concentrate powder is usually uranium oxide, U₃O₈, commonly called “yellowcake”. This material, which contains 70 to 82% uranium, is packed and shipped in metal drums for refining and conversion. Refining and conversion services are performed in Ontario, Canada by the Fuel Services Division of Cameco Corporation.
Refining to UO₃

Cameco's Blind River Refinery receives drums of uranium ore concentrate from mines in Canada, Australia, the United States, Commonwealth of Independent States, Africa and other countries worldwide. Uranium is separated from impurities contained in the mine concentrates in a refining process using digestion, solvent extraction, denitration and other processes. The result is a nuclear grade uranium product known as uranium trioxide (UO₃).

Sampling and Feed Preparation:

The Blind River Refinery receives various types of uranium mine concentrates such as diuranates or uranium oxides which may or may not be calcined. Mine concentrates are shipped to the Refinery via truck in 205 litre (45 imperial gallon) drums. For contractual and processing reasons it is necessary to accurately sample and measure the uranium content of the concentrates as well as impurities to ensure compliance with concentrate specifications. These data are also used to account for all radioactive materials and comply with regulatory requirements. Sampling of the concentrates is done in two stages: In the first step, each drum is sampled using a small auger followed by a sample splitter. In the second step, the original samples are further subdivided by splitting and combining to composite samples for a delivered lot. These samples are analyzed for uranium and impurities by both Cameco and the producing mine. In the event of significant differences in results, a third-party "umpire" analysis is carried out and the result used for a final decision.

The chemical properties of the uranium concentrates are governed by specifications and the characteristics of individual mine concentrates will usually show little variation.

Digestion:

The next step in the refining process is "digestion". Concentrates are added to a nitric acid solution in a continuous two-stage, reactor system. Concentrates are digested at 70° to 90°C. The resulting acidic uranyl nitrate solution, also containing dissolved impurities, is stored in tanks and then metered to the solvent extraction plant.
SOLVENT EXTRACTION:

After digestion the impure uranyl nitrate solution is introduced to a purification process called “solvent extraction”. This process separates dissolved uranium from the aqueous uranyl nitrate solution utilizing a solvent and the unequal distribution of the uranium between the two immiscible liquids. The process occurs in a counter-current multi-stage vertical column, the extraction column. The solvent used for extracting the uranyl nitrate from the acidic solution is a tributyl phosphate (TBP) dissolved in a kerosene diluent, commonly called “organic”. The organic enters the bottom of the column and the aqueous feed solution is introduced at the top. Due to differences in density the aqueous uranyl nitrate feed solution flows downward and the organic, rises to the top of the column. The two solutions are mixed and separated many times over the length of the column resulting in the organic extracting the uranyl nitrate. The impurities and excess acid are discharged at the bottom of the extraction column as an aqueous stream, which is called “raffinate”.

The loaded organic leaving at the column top then goes to the scrubbing column, where the uranyl nitrate/organic mixture is contacted, with a small amount of water in a counter-current flow to remove residual impurities. The bottom aqueous product, containing scrubbed impurities is recycled to the digestion stage to recover the acid and uranium.

The loaded and scrubbed organic, carrying the pure uranyl nitrate is then forwarded to the stripping column, where it is contacted with a relatively large flow of recycled processed condensate. This results in the stripping (reextraction) of uranium from the organic. The resulting nuclear grade uranyl nitrate solution (“OK Liquor”) is the feed stock for the next process step.

URANIUM CONCENTRATION: (BOILDOWN)

The nuclear grade uranyl nitrate solution (“OK Liquor”) discharged from the strip column is pumped to a three-stage evaporator system where water is evaporated and the uranium concentration is increased from ~100 gU/L to ~1200 gU/L. At this high uranium concentration the uranyl nitrate solution roughly represents molten uranyl nitrate hexahydrate (UNH) which is kept hot to keep it in the liquid state. UNH is fed to the denitration process to convert it to the final UO₂ product.
Mine Ore

Mill

Shipment to Refinery
"Yellow Cake"

Weighing and Sampling

Nitric acid

3-Stage Digestion

Blind River Refinery
REFINING TO UO₃

Solvent Extraction → Water → TBP Solvent → Recycle to Digestion

OK Liquor → ACID RI

Steam → Drum Calculator

Truck Transport
Shipping to Refinery
"Yellow Cake"

Mine

Ore

T Mill

3-Stage Digestion

Weighing and Sampling

Blmci River Refinery
SOLVENT EXTRACTION:

After digestion the impure uranyl nitrate solution is introduced to a purification process called "solvent extraction". This process separates dissolved uranium from the aqueous uranyl nitrate solution utilizing a solvent and the unequal distribution of the uranium between the two immiscible liquids. The process occurs in a counter-current multi-stage vertical column, the extraction column. The solvent used for extracting the uranyl nitrate from the acidic solution is a tributyl phosphate (TBP) dissolved in a kerosene diluent, commonly called "organic". The organic enters the bottom of the column and the aqueous feed solution is introduced at the top. Due to differences in density the aqueous uranyl nitrate feed solution flows downward and the organic, rises to the top of the column. The two solutions are mixed and separated many times over the length of the column resulting in the organic extracting the uranyl nitrate. The impurities and excess acid are discharged at the bottom of the extraction column as an aqueous stream, which is called "raffinate".

The loaded organic leaving at the column top then goes to the scrubbing column, where the uranyl nitrate/organic mixture is contacted, with a small amount of water in a counter-current flow to remove residual impurities. The bottom aqueous product, containing scrubbed impurities is recycled to the digestion stage to recover the acid and uranium.

The loaded and scrubbed organic, carrying the pure uranyl nitrate is then forwarded to the stripping column, where it is contacted with a relatively large flow of recycled processed condensate. This results in the stripping (reextraction) of uranium from the organic. The resulting nuclear grade uranyl nitrate solution ("OK Liquor") is the feed stock for the next process step.

URANIUM CONCENTRATION: (BOILDOWN)

The nuclear grade uranyl nitrate solution ("OK Liquor") discharged from the strip column is pumped to a three-stage evaporator system where water is evaporated and the uranium concentration is increased from ~100 gU/L to ~1200 gU/L. At this high uranium concentration the uranyl nitrate solution roughly represents molten uranyl nitrate hexahydrate (UNH) which is kept hot to keep it in the liquid state. UNH is fed to the denitration process to convert it to the final UO₂ product.
DENITRATION:

In denitration, hot molten uranyl nitrate hexahydrate (UNH) is converted to UO₃ powder. Molten UNH from boildown is metered to continuously operated and electrically heated stirred pot denitrators where the UNH is thermally decomposed to uranium trioxide (UO₃), oxides of nitrogen (NOₓ), and water vapour. The NOₓ off-gas is piped to a nitric acid recovery plant.

UO₃ powder discharged continuously from the denitrators is transferred to the shipping tote bins. These tote bins are then forwarded to the Port Hope Conversion Facility where the UO₃ is used to produce uranium hexafluoride (UF₆) for enrichment plants and/or uranium dioxide (UO₂) for nuclear fuel production (CANDU fuel), or blanket fuel for light-water reactors.

RAFTINATE TREATMENT:

Raffinate from the extraction column is fed to the raffinate treatment circuit. Here, the bulk of contained water and acid is evaporated in two stages of evaporation to produce a dense slurry composed of mainly metal nitrates. The metal nitrate slurry is then dried in drum dryers to produce a powder with a low moisture content which is subsequently processed in a rotary calciner where the metal nitrates decompose to metal oxides and a nitrogen oxide off-gas (NOₓ). The metal oxides, containing residual small amounts of uranium are recovered as a free-flowing calcined powder which is drummed and stored for shipment back to uranium mills for recycle. The off-gas from the calciner is fed to the nitric acid recovery plant. The overheads from the raffinate evaporators, dilute nitric acid vapors, are piped to an acid concentrator where the nitric acid is brought up to 50-55%. The “by-product”, condensate obtained from concentrator overheads, is discharged to the effluent lagoons after neutralization to pH7.

NITRIC ACID RECOVERY:

The acid absorbers recover nitric acid from NOₓ off-gases from the digestion and denitration areas of the UO₃ production process. These gases are fed to multi-stage absorber columns where the NOₓ is absorbed in cold water to produce nitric acid at the concentration of 30-45% which is combined with acid recovered from the nitric acid concentrator in the raffinate area.

The combined acid is recycled back to the initial digestion stage, to dissolve concentrates.
**UF₆ PRODUCTION**

The uranium trioxide (UO₃) produced at the Blind River Refinery is shipped to Port Hope in “specially designed” tote bins. The bins hold 9.5 tonnes of uranium for conversion into either uranium hexafluoride (UF₆) or ceramic-grade uranium dioxide (UO₂). Approximately 80 percent of the UO₃ produced at the Blind River Refinery is converted by a chemical process to UF₆ which is exported to enrichment plants abroad. The remaining 20 percent is used to supply CANDU reactors with ceramic-grade uranium dioxide.

**CONVERSION TO UF₆**
REDUCTION:

In the first process step of the U\textsubscript{3}O\textsubscript{8} process, UO\textsubscript{2} is pulverized to a fine powder which is fed into a two-stage fluidized bed reactor system which uses hydrogen gas to reduce the UO\textsubscript{2} powder to UO\textsubscript{2}.

HYDROFLUORINATION:

In the second process step, the UO\textsubscript{2} powder is fed to "wet" reactors. Hydrogen fluoride (HF) and dilute aqueous hydrofluoric acid, recycled from Cameco's acid recovery system, are added to convert the UO\textsubscript{2} to uranium tetrafluoride (UF\textsubscript{4}). The resulting UF\textsubscript{4} slurry is then pumped to drum dryers which remove most of the water. From the drum dryers, the UF\textsubscript{4} passes into calciners which operate at a temperature of 450°C to remove the final traces of free and hydration water.

FLUORINATION:

In the third process step, the calcined UF\textsubscript{4} powder is reacted with fluorine gas in co-current top to bottom flow vertical shaft reactors known as flame reactors. This process produces uranium hexafluoride (UF\textsubscript{6}) gas. For this process, Cameco produces its own fluorine gas using electrolytic cells which contain molten potassium bifluoride and HF. A 12,000 ampere electric current is applied to dissociate HF into hydrogen and fluorine. These gases are collected separately and the fluorine is used to convert the UF\textsubscript{4} to UF\textsubscript{6} gas in the flame reactor system. Hydrogen is scrubbed, to remove residual HF, and discharged to the atmosphere.