SEU Blending Project
Concept To Commercial Operation

Part 3: Production Of Powder For Demonstration Irradiation Fuel Bundles

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ABSTRACT

The processes for production of Slightly Enriched Uranium (SEU) dioxide powder and Blended Dysprosium and Uranium (BDU) oxide powder that were developed at laboratory scale at Cameco Technology Development (CTD), were implemented and further optimized to supply to Zircatec Precision Industries (ZPI) the quantities required for manufacturing twenty six Low Void Reactivity (LVRF) CANFLEX fuel bundles.

The production of this new fuel was a challenge for CTD and involved significant amount of work to prepare and review documentation, develop and approve new analytical procedures, and go through numerous internal reviews and audits by Bruce Power, CNSC and third parties independent consultants that verified the process and product quality. The audits were conducted by Quality Assurance specialists as well as by Human Factor Engineering experts with the objective to systematically address the role of human errors in the manufacturing of New Fuel and confirm whether or not a credible basis had been established for preventing human errors. The project team successfully passed through these audits.

The project management structure that was established during the SEU and BDU blending process development, which included a cross-functional project team from several departments within Cameco, maintained its functionality when Cameco Technology Development was producing the powder for manufacturing Demonstration Irradiation fuel bundles. Special emphasis was placed on the consistency of operating steps and product quality certification, independent quality surveillance, materials segregation protocol, enhanced safety requirements, and accurate uranium accountability.

1.0 SEU BLENDING PROJECT OVERVIEW

To enhance the safety of CANDU reactors and allow their use at full design capacity, Bruce Power initiated New Fuel project [1]. The concept of New Fuel, developed by Atomic Energy of Canada Limited (AECL), is based on a 43-element CANFLEX® LVRF (Low Void Reactivity Fuel) bundle consisting of forty-two fuel rods with slightly enriched (up to 2.5 wt% ^{235}U) uranium dioxide (SEU) pellets and a center pin with $(Dy,U)O_2$ (BDU) pellets [2].

The background of SEU Blending Project, Project management and execution plan, and methodology for SEU and BDU products development including initial progress on development of blending process were discussed in detail elsewhere [3, 4]. Cameco, together with its commercial partners, Bruce Power and Zircatec Precision Industries, played a key role in the development of blending processes for the production of SEU-UO_2 and BDU powders that were used for manufacturing 26 CANFLEX® LVRF bundles for Demonstration Irradiation (DI).

Although the materials produced at Cameco today are mainly natural uranium dioxide, UO_2, and uranium hexafluoride, UF_6, there is extensive experience of working with enriched uranium, even up to 93 wt% ^{235}U, levels. In the past, Cameco produced enriched UO_2 for tests conducted at AECL.

The production of powder for manufacturing the SEU pellet is based on dry blending of commercial nuclear-grade Low Enriched Uranium (LEU) dioxide powder (3 to 5 wt% ^{235}U) with ceramic-grade natural uranium dioxide powder. Similarly, the powder for manufacturing BDU pellets is produced by blending commercial Dy_2O_3 powder with the natural ceramic UO_2 powder. Cameco's ceramic-grade natural UO_2 powder (NU-UO_2) is known as the best commercial material of this type in the world because of its high purity and excellent sinterability.

In addition to the experience of many years of commercial production of ceramic natural UO_2 powder, Cameco also has another strength required for successful development of a new fuel, Cameco Technology Development (CTD) department that employs scientists and technologists with the background in chemistry, metallurgy, ceramics, geochemistry, as well as material analysis and diagnostics.

All these played an important role in facilitating successful development of the process for producing two new blended powder products, SEU and BDU (Blended Dysprosium and Uranium oxides) for the LVRF bundles. In addition to the development of blending technology and evaluating the powders on bench scale, the product development objectives included production of a few hundred kilograms of these two new powders for making fuel bundles at Zircatec Precision Industries for Demonstration Irradiation program at Bruce Power.

2.0 CHALLENGES IN THE DEVELOPMENT OF SEU BLENDING PROCESS

2.1 License Limits to Handle Low Enriched UO_2 Powder

The development of SEU blending process at Cameco was started in October 2002 with a 100 g sample of LEU-UO_2 powder with an enrichment of 4.4 wt% ^{235}U. Because of the initial license limit of 100 gU, LEU samples received from different suppliers were temporarily stored at Zircatec. After testing and characterization, each sample of LEU-UO_2 powder from a particular supplier, as well as the SEU blends prepared from this powder and scrap and waste, had to be sent to Zircatec for storage before receiving the next 100-g sample of LEU-UO_2.

To carry out laboratory-scale SEU blending tests, Cameco received an amendment to the Facility Operating License for Port Hope Fuel Services that allowed handling LEU and SEU. The maximum quantities of special materials that will be on site at any one time and that will be used by CTD are; 30% of the smallest critical mass (SCM) of enriched uranium compounds with a maximum of 5% ^{235}U.

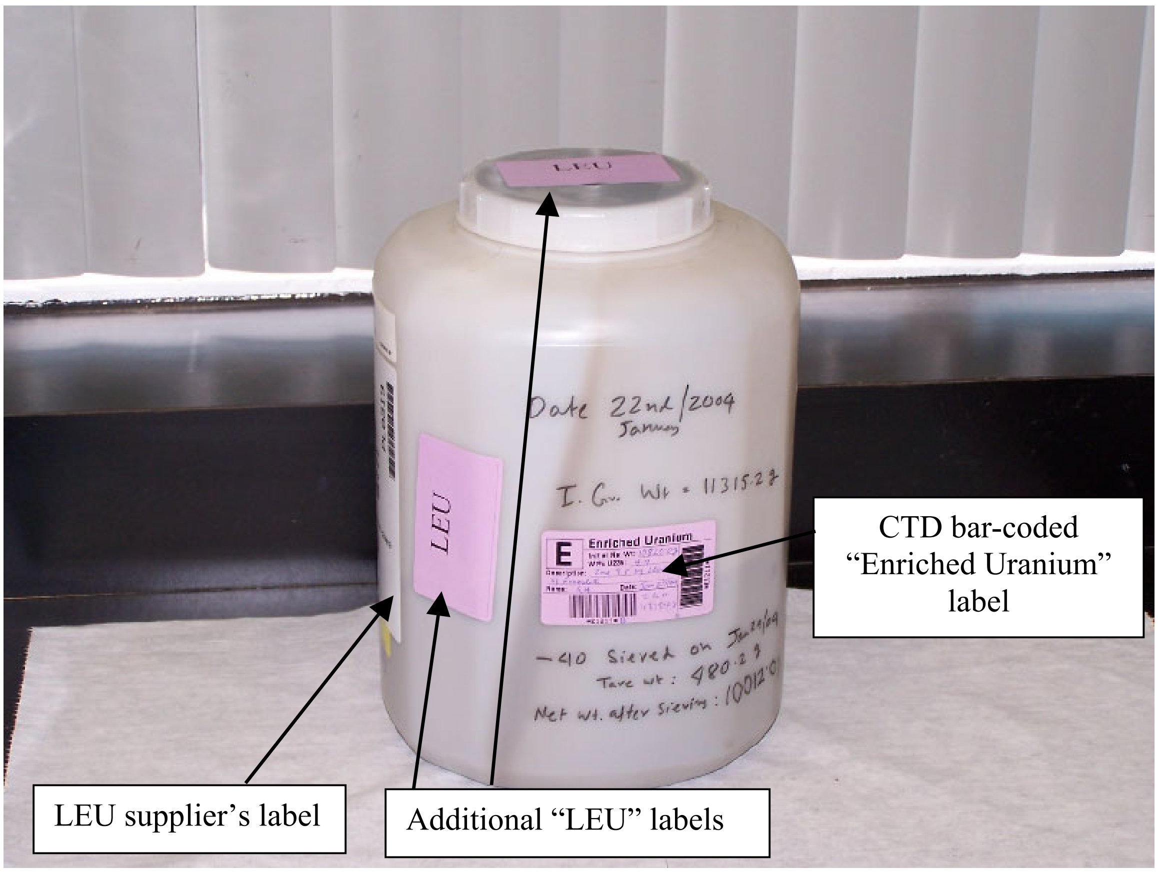
2.2 SEU Blending Process Development

Approximately 80 kg of LEU-UO_2 powder enriched to less than 5 wt% ^{235}U was purchased in the USA for the production of SEU powder to fabricate twenty-six DI fuel bundles. The development of SEU blending process for DI was carried out as a sequence of steps involving testing and optimization of several types of blenders and mills in accordance with a flowsheet developed at bench scale test programs. Some equipment was modified to increase the original production capacity by more than two orders of magnitude. To achieve the macroscopic and microscopic homogeneity in SEU powder, the team required additional equipment and new operating procedures.

Figure 1. Blending SEU powder for DI

Special procedures were also developed that would also cover health and safety issues and nuclear criticality safety, as well as the material segregation protocol to prevent cross contamination of the Port Hope conversion facility with enriched uranium or dysprosium. The process development work was carried out in a dedicated lab, but at the same time in a commercial plant environment so that all necessary measures were taken to prevent contamination of the production circuits with the new materials.

New software was developed to calculate the weight of source powders for blending. To minimize human error, the balances for weighing the source powders were interfaced to a computer and the software was developed to verify the blend composition. A detailed LTSO (Laboratory Test Circuit Safety and Operability) manual was prepared that described process steps and included process safety analysis. Inspection and Test Plan (ITP) was developed for



SEU powder blending and approved by Bruce Power.

Figure 2. Plastic container with SEU powder

Scientists and technologists were fully dressed; it was assessed that the design of the laboratory and equipment, together with the use of personal protective tools, would provide safe and clean working environment and ensure that the potential for cross contamination is minimized and collecting work place hygiene environment data could be possible during the development work. This was considered as prudent way conducting the test work with the intention of developing procedures for handling these products in the commercial production.

The production circuit and procedures developed ensured that SEU powder for DI was produced according to the ITP and on schedule and met the specification. The process audits carried out by 3rd parties did not reveal any findings or deficiencies related to Quality Assurance (QA) or Human Factor Engineering (HFE). The audits were an important condition for SEU powder acceptance by Bruce Power. This information was also used as design criteria for commercial circuit engineering design.

Figure 3. Loading the bottles with SEU powder into ANF250 shipping container

2.3 Development of SEU Specifications

Cameco developed SEU powder specification for DI to meet the list of impurities in SEU pellet specification. The source powders selected for the test work had high purity to ensure that the product quality would be acceptable and the production activities would be completed on schedule. In addition to the list of impurities and limits, the specification defined the physical characteristics of sinterable SEU-UO_2 powder. This Specification for SEU powder allowed the project to start, although it was understood at that time that future commercial production of SEU-UO_2 and BDU powders would require updates based on comprehensive market research. Cameco recommended AECL, Bruce Power and Zircatec to revise the limits on impurities in the SEU pellet and powder specifications, based on the fuel performance parameters and analysis of LEU powder available in the market, to protect the future commercial SEU powder supply from non-conformance that might result from the impurity in LEU and provide flexibility for sourcing LEU-UO_2 powder, while ensuring safety for the fuel use and storage.

2.4 Measuring Macroscopic Homogeneity of SEU

A definition of macroscopic homogeneity of uranium isotopic composition was required for the safety analysis at Bruce Power.
Cameco developed a definition of macroscopic homogeneity of SEU powder based on the distribution of LEU agglomerates and carried out analysis of various sampling plans to minimize the analytical cost. An analytical procedure to measure the macroscopic homogeneity of SEU was developed and included in the Inspection and Test Plan (ITP) for the production of SEU powder for DI. The procedure was approved by Bruce Power and used at CTD to certify SEU powder for DI. It is expected this analytical procedure, with a possible minor modification, will be applied to certify SEU powder in commercial production.

2.5 Measuring Microscopic Homogeneity of SEU

Definition of microscopic homogeneity of SEU pellets was needed for Bruce Power to evaluate the fuel performance and develop safety analysis. Therefore, Cameco took the initiative to define the microscopic homogeneity of SEU powder to be used for the pellet manufacturing.

Cameco developed a definition of microscopic homogeneity of SEU powder based on the examination of size distribution of LEU agglomerates in sintered SEU pellets. The analytical technique selected for this purpose involved Secondary Ion Mass Spectrometry (SIMS). The samples for SIMS analysis are prepared in the CTD lab and the measurements are carried out in a specialized laboratory. The algorithm that is based on statistical models and the software developed at CTD for SIMS data processing allow evaluations to be made regarding hot spots formation in fuel elements at microscopic level. The technique was reviewed and accepted by Bruce Power experts. The solution of this problem gave a tool to the Fuel Safety Analysts at BP to evaluate the fuel performance, which was the basis for giving “green light” for the project team to proceed with the process development.

The analytical procedure and criteria for microscopic homogeneity of SEU were used at CTD as a benchmark to develop SEU blending process that produced acceptable quality SEU powder and to certify five SEU batches for the manufacturing of CANFLEX LVRF bundles for Demonstration Irradiation. All five SEU batches had the macroscopic homogeneity that met with significant safety margins the requirements of Bruce Power.

2.6 Monitoring and Maintaining LEU and SEU Accountability

Both LEU and SEU are safeguarded materials. CNSC and IAEA requested to keep accountability of those materials minimum up to one-gram scale. Taking into account the number of tests and samples involved in the SEU blending process development and production of SEU powder for Demonstration Irradiation, maintaining the LEU inventory required development of a dedicated database, maintaining the database and reporting at anytime required in real time. Cameco developed software for LEU inventory that recorded the information on source LEU powders, SEU blends, analytical samples, as well as scrap and waste materials. The records contain information about material composition and type, ^{235}U enrichment, weight, location and date of blending or sampling. The database automatically calculates a smallest critical mass for LEU and SEU materials on-site and keeps track of genealogical relations between the records for SEU product or samples and parent materials. It has extensive search capabilities, provides data filtering and generates reports.

During the test program, shipping and receiving of LEU and SEU containing materials was coordinated with the Criticality Control Committee and Logistics Department. All the records on the quantities and composition of LEU and SEU powders and samples were maintained in a dedicated computer database. The summary reports on LEU and SEU quantities were compared on a monthly basis with the LEU ledger for the site and reported to CNSC. The inventory was audited twice a year by CNSC and IAEA. Internal mini-audits were carried out four times a year.

The development and implementation of the LEU accountability procedure and LEU/SEU database at CTD allowed the SEU project team to maintain a good record and successfully pass through numerous inventory audits conducted by CNSC and IAEA, as well as QA and HFE audits carried out by Bruce Power and consultants. As a result, no disruption occurred to the SEU blending process development and powder production schedule. The material accountability procedure helped the team to prove the high quality of materials handling at CTD, low risk of mixing up the powders and other human errors, and virtually eliminated the potential for cross contamination.

3.0 CHALLENGES IN THE DEVELOPMENT OF BDU BLENDING PROCESS

3.1 BDU Blending Process Development

Similar to SEU, the development of BDU blending process for DI involved testing and optimization of several types of blenders and mills in accordance with a flowsheet developed within laboratory test program. One of the major challenges in BDU blending process was the requirement for a very high level of macroscopic and microscopic homogeneity to ensure the formation of BDU solid solution during pellet sintering. New operating procedures, as well as the material segregation protocol were developed to prevent cross contamination of SEU and Port Hope conversion facility with dysprosium. The process development work was carried out in a dedicated laboratory so that dysprosium-containing materials were never brought to the SEU lab nor to the ceramic UO_2 production Plant. The material segregation procedure was developed and approved by Bruce Power. New software was developed to calculate the weight of source Dy_2O_3 and NU-UO_2 powders for BDU blending. A detailed BTSO (Bench Test Circuit Safety and Operability) manual was prepared that described process steps and included process safety analysis. Inspection and Test Plan (ITP) was developed for BDU powder production and approved by Bruce Power.

The production circuit and procedures developed ensured that BDU powder for DI was produced according to the ITP and on schedule and met the specification. The process audits carried out by 3rd parties did not reveal any findings or deficiencies related to QA or HFE. The audits were an important condition for BDU powder acceptance by Bruce Power. The processing information developed was also used as design criteria for commercial circuit engineering design.

Figure 4. Overpacks for shipping BDU powder for DI

One of the major activities involved in the process development was characterization of BDU powder and sintered pellets. There are very few publications on the UO_2–Dy_2O_3 system and they did not provide sufficient information to identify the properties of BDU powder and sintered pellets. Therefore, a number of new analytical techniques were developed at CTD and Cameco Analytical Services to measure macroscopic and microscopic homogeneity and composition of BDU powder and pellets, impurities and other characteristics to ensure good quality of the blends.

3.2 Development of BDU Specifications

New specification was developed for BDU powder to meet the list of impurities and other parameters in BDU pellet specification and initiate the production of BDU powder for DI. There is no “Nuclear-Grade” dysprosium oxide on the market and no consistent specification exists for defining the quality of dysprosium oxide powder. Currently Cameco is in process of making recommendations to AECL and Bruce Power on the limits on impurities in the BDU pellet and powder specifications, based on the fuel performance parameters and experience of producing BDU powder for DI. Discussions with potential suppliers of Dy_2O_3 powder have been initiated to define specifications for “nuclear-grade” dysprosium oxide to be used for BDU blending.

During the development of BDU sintering process, the aging phenomenon of BDU sintered pellets was discovered and the technology was suggested to produce stable BDU pellets by increasing the oxygen potential in sintering atmosphere. The technology and sintered pellet characteristics were discussed at a series of meetings involving Cameco, Zircatec, AECL and Bruce Power to define the parameters that are critical for the production and certification of good quality BDU pellets.

3.3 Monitoring and Maintaining Dysprosium Accountability

Both Dysprosium Oxide (Dy_2O_3) and BDU contain dysprosium, which is a neutron absorber. Cameco specification CS1 for natural uranium dioxide powder includes the maximum allowable limit for dysprosium at 0.30 ppm, U basis. Therefore, maintaining the Dy_2O_3 and BDU inventories was one of the tasks helping to prevent loss of those materials, which could potentially result in contamination of the commercial operations at site.

Cameco developed material accountability and segregation procedures for Dy-containing materials and followed them during BDU powder preparation for DI. The procedures and practices were audited by Quality Assurance auditors, Quality Surveillance representative and Human Factors Engineering auditors, which was one of the conditions for the powder acceptance by Bruce Power. No findings or deficiencies were identified.

The implementation of material accountability and segregation procedures allowed the project team to meet the QA requirements and specifications, and minimized or eliminated potential for cross contamination.

4.0 PRODUCTION OF SEU AND BDU POWDERS

The development of SEU and BDU blending processes and production of powders for the manufacturing of DI fuel bundles were implemented in coordination with the Production, Technical Services and Transport departments of Cameco Conversion Facility in Port Hope, Ontario. The safety requirements to handle LEU powder included a new ventilation system with five Goretex and HEPA filters installed in series, personal protective equipment that would not only minimize the operators exposure to UO_2 or BDU dust, but also reduced a possibility of material cross contamination through clothes, additional training on nuclear criticality for the technical personnel related to the SEU blending project. The fact that the SEU and BDU powder from prototype production would be used for manufacturing LVRF bundles for the Bruce Power reactor, demanded a high level of quality assurance and documentation. The implementation of material accountability and segregation procedures allowed the project team to meet the QA requirements and specifications, and minimized potential for cross contamination.

For transportation of the LEU and SEU powders, twenty-four ANF-250 shipping containers were rented for the duration of the SEU blending program. The containers are also being used for temporary storage of SEU powder before the fuel bundle fabrication.

To better understand the quality of LEU and the production capacity available in USA and abroad, Cameco representatives visited a number of nuclear conversion facilities to ensure that the Cameco Quality Standards can be met when commercial production of blended SEU powder is started. The visits were also helpful to observe different safety practices of material handling, organizing the workplace, infrastructure and transportation, ensuring nuclear criticality safety, material segregation, and waste processing.

With the beginning of the SEU blending project, four new materials were introduced on-site, which were LEU, SEU, BDU, and Dy_2O_3. Therefore, material segregation and development of the operating and material handling procedures that would eliminate a risk of cross contamination were a priority since the bench scale tests were initiated. To prevent cross contamination or mixing up the materials, the SEU and BDU operations were carried out in different laboratories on different dates and using different equipment, containers and labels. The same group of scientists and technologists who developed the blending processes carried out the SEU and BDU production operations.

Figure 5. Different shape plastic containers for BDU (left) and SEU (right) powders

Traditionally, natural uranium oxide scrap and waste materials are treated in the solvent extraction circuit at Cameco's Blind River Refinery (BRR). For the BDU scrap, substantial test work was carried out, which indicated that dysprosium could be successfully removed using the existing BRR circuit. Therefore, the BDU-originated scrap and waste materials that contain only natural uranium will be processed at Blind River.

5.0 CONCLUSIONS

SEU and BDU blending technology was developed to successfully produce 640 kg of SEU powder and 24 kg of BDU powder meeting the target specifications. All SEU and BDU powders were shipped to fuel fabricator, Zircatec, for manufacturing 26 fuel bundles for DI.
The SEU Blending project contributes to the New Fuel Project for Bruce Power, which brings together four companies Bruce Power, AECL, Cameco and Zircatec as well as numerous consulting companies with the objective to increase the energy production from the existing CANDU reactors and enhance their safety. It introduces a new level of cooperation between the producers of uranium powder, fuel fabricators and nuclear utilities because the challenging tasks of commercialization of the new fuel have to be implemented in a relatively short period of time. The project team through all facets of the project development activities is striving to meet the high standards of safety, minimum impact on the environment, consistent product quality and an economical process design to ensure a successful completion of the project.

6.0 ACKNOWLEDGEMENTS

The project required coordination of activities of several companies and a number of consultants and coordination of various departments within Cameco. In particular, the following departments at Cameco have and are making significant contributions to the successful development of the project; Cameco Technology Development (CTD), Mineralogy and Chemical Analysis Laboratory of CTD (MCAL), Analytical Services PHCF, Analytical Services BRR, Compliance and Licensing PHCF, Technical Services PHCF, Production PHCF, Engineering and Maintenance PHCF, Accounting and Purchasing PHCF, Materials Handling/Transportation PHCF, Public Relations/Communications, PHCF and Corporate Office, Safety, Health and Environment Division, Legal Department, Corporate Development and Marketing Division.

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