SEU Blending Project
Concept To Commercial Operation

Part 4: Engineering Design

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ABSTRACT

The process development test program for production of Slightly Enriched Uranium (SEU) dioxide powder and Blend of Dysprosium and Uranium (BDU) oxide powder was initiated almost simultaneously with the conceptual engineering study for the commercial plant in 2001. During the very early phases of the project it was recognized that meeting the challenging requirements would necessitate wide expertise from different departments within the Cameco operations as well as consultants from outside the Company. The project team formed reflected this recognition. The conceptual engineering study was the lead into preparation of the engineering design study in 2003, which provided the process description based on the research and development program being carried out at Cameco Technology Development (CTD), project description, and project cost estimates. The detailed engineering phase commenced in June 2004 and was in progress at the the time when this paper was presented. The detailed engineering phase is addressing all aspects of the commercial plant including all health and safety, environment and security related issues, nuclear safety, training program, all product quality assurance issues, quality management issues, powder and fuel bundle transportation issues, all regulatory requirements, establishing project execution plans and budget, and strategies to control the costs. At the end of the detailed engineering phase, construction packages will be ready for tender, and major pieces of equipment will be selected and procured.

1.0 INTRODUCTION

Cameco Corporation (Cameco) will be establishing an operation at its existing Port Hope Conversion Facility (PHCF) for the dry blending of natural uranium dioxide (NU) with low-enriched uranium dioxide (LEU), to produce slightly-enriched uranium dioxide (SEU), for use as fuel in CANDU (Canada Deuterium Uranium) reactors. Hereafter in this paper, all forms of uranium (NU, LEU, SEU) are considered to be uranium dioxide unless otherwise indicated.

The term slightly enriched uranium dioxide (SEU) describes a uranium dioxide in which the U-235 content of the uranium is between 0.711% to 2.5%. This composition is enriched in U-235 content compared to natural uranium which has a U-235 content of 0.711 % on a total U basis. SEU is below the 3% to 5% enrichment range, usually referred to as low-enriched uranium (LEU), that is typically used to describe the fuel used in light-water reactors and produced for such reactors outside Canada.

The project also includes the production of commercial quantities of blended dysprosium oxide and natural uranium dioxide (BDU) powder also for use in fuel bundles in reactors. Dysprosium oxide is a non-radioactive rare earth metal oxide. Dysprosium oxide has the ability to absorb neutrons, and hence is used in the nuclear industry. The BDU will be processed in a separate, self-contained area in the building proposed for SEU blending.

To develop this multi-facetted project requiring high standards of health and safety, environmental and product quality requirements, Cameco has formed an integrated design team with a wide range of skills and experience base. Members of the Cameco team are from various departments within the organization, including production, maintenance, engineering, technology development and technical services. Cameco has contracted outside engineering and construction contractor SNC-Lavalin to perform the engineering design and construction work, as well as various other specialty consultants to provide technical assistance in areas such as criticality safety control and fire safety, and human factors engineering.

The engineering design development of the project has been divided into three main phases. The first phase was the conceptual engineering design initiated in 2001. During this phase basic concepts of the process were determined and preliminary flowsheets and cost estimates were developed. The second phase of engineering development was the engineering design study phase. During this phase P&ID's, revised flowsheets, equipment specifications and a more accurate cost estimate were developed. The project is now advancing into the detailed engineering, procurement and construction phase (EPCM phase). During this phase the equipment specifications and selections are being finalized to prepare for procurement and plans are being developed to construct the plant. The construction is scheduled to begin in mid 2006, with production of SEU to be achieved in second half of 2007.

The SEU and BDU, which will be produced at Cameco, will be incorporated into a new CANFLEX fuel bundles at Zircatec Precision Industries for use in the reactors at the Bruce Power nuclear facility. The SEU will be used in fuel elements surrounding a centre element containing the neutron-absorbing BDU. This results in a low void reactivity fuel, which will be referred to as SEU Fuel. The SEU Fuel will allow the Bruce "B" reactors to run at full reactor power. This project is called the "New Fuel" project at Bruce, and involves a group of four companies, namely Bruce Power, AECL, Zircatec Precision Industries, and Cameco Corporation.

2.0 PROJECT MANAGEMENT

2.1 Overall Project Team

The New Fuel Project consolidates the activities of four major participants; Bruce Power, Cameco, Zircatec and AECL. Each company has formed internal teams to develop the project. These teams communicate and interact on a regular basis to ensure overall project coordination is maintained. To coordinate Cameco's involvement in the project, the organization structure put together is shown below in Figure 1.

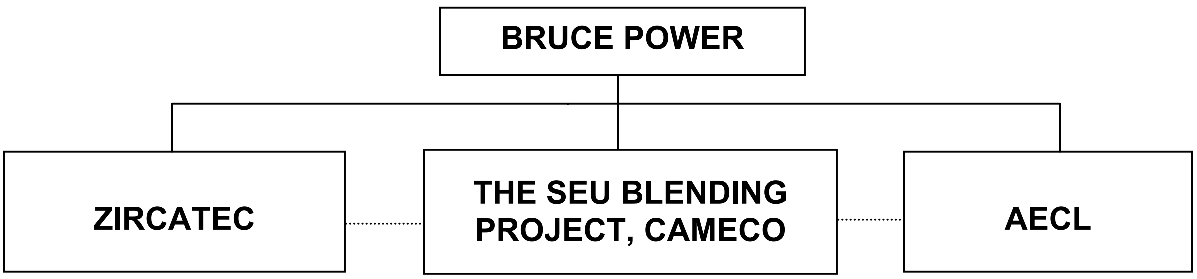

Figure 1. SEU Blending Project Organization

2.2 Cameco Project Team

In the early phases of the project, Cameco recognized that a strong, interdisciplinary team was essential to ensure the project requirements are met. Throughout all phases of this project, many employees have been involved from fuel services, health and safety, environment, corporate development, Cameco technology development, marketing and legal to ensure all requirements of the project are satisfied. The team make-up during each phase of the project is described in later sections.

2.3 Consultants

To enhance the skills base of the cross functional interdiscipnary Cameco team, a number of outside consultants were also hired to provide the engineering design, planning, cost estimating, scheduling and installation and construction of project facilities. SNC Lavalin has been contracted as the general engineering contractor for this project. They are providing the engineering resources required to design and construct the facility. As well, Cameco has retained a number of specialized technical consultants to provide input into areas such as criticality safety, Enviromental Assesment Study development and fire safety. In the early stages of the project Consultants were brought in to train the Cameco project team members on Criticality Safety and safe handling of enriched uranium integrating as well as human factor engineering principles to the design of the entire facility. . Throughout the engineering design development of the SEU blending plant project the overall designs and layouts have been reviewed by various criticality safety experts to ensure that criticality safety design principles are incorporated into the plant design. Criticality safety training has also been provided to various consultants to ensure that the criticality awareness is incorporated into the design.

3.0 ENGINEERING DESIGN DEVELOPMENT

3.1 Conceptual Engineering Design Phase

3.1.1 Objective

The objective of the conceptual engineering design was to prepare the preliminary flowsheets and layouts, and develop the budgetary cost estimate based on the limited information developed during the bench scale test program at CTD. Development of a preliminary schedule, and determination of key environmental and regulatory issues were also a focus of the conceptual design. The conceptual design phase was carried out in 2001 and 2002, first by Cameco's internal engineering resources and then involving an outside consulting engineering company.

3.1.2 Cameco Project Team

During the conceptual design phase, Cameco formed an interdiscipilinary team to develop the project. Over 20 employees were involved to form the conceptual design project team. The overall team structure for the conceptual engineering development is shown in Figure 2. Within the teams, sub teams were formed to address issues such as Quality Assurance. The quality assurance team met on a regular basis and developed the product specifications, Inspection Test Plans and quality standards. Also committees, such as the Criticality Control Committee (CCC), were formed to support the SEU lab development work and future commercial production. The CCC meets on a regular basis, and is formed as an interdisciplinary group of Cameco employees, as well as a consulting criticality safety expert.

3.1.3 Outcome

A preliminary cost estimate, schedule, flowsheets and layouts were produced. These documents allowed for the regulatory process to begin through the submission of a project proposal to the Canadian Nuclear Safety Comisssion, and formed the basis of the next phase of engineering design development work.

3.2 Engineering Design Study Phase

3.2.1 Objective

The objective of the engineering design study phase was to further develop the layouts and flowsheets, develop P&ID's, equipment specifications, detailed schedules, construction plan and cost estimates. Preparation of the Environmental Assessment study report, as well as a hazard and operability review (HAZOP) of the project were included in the objectives of this phase. The project development was based on the information being developed during the comprehensive test program results at CTD and Cameco's experience and knowhow of many years of uranium oxide powder production.

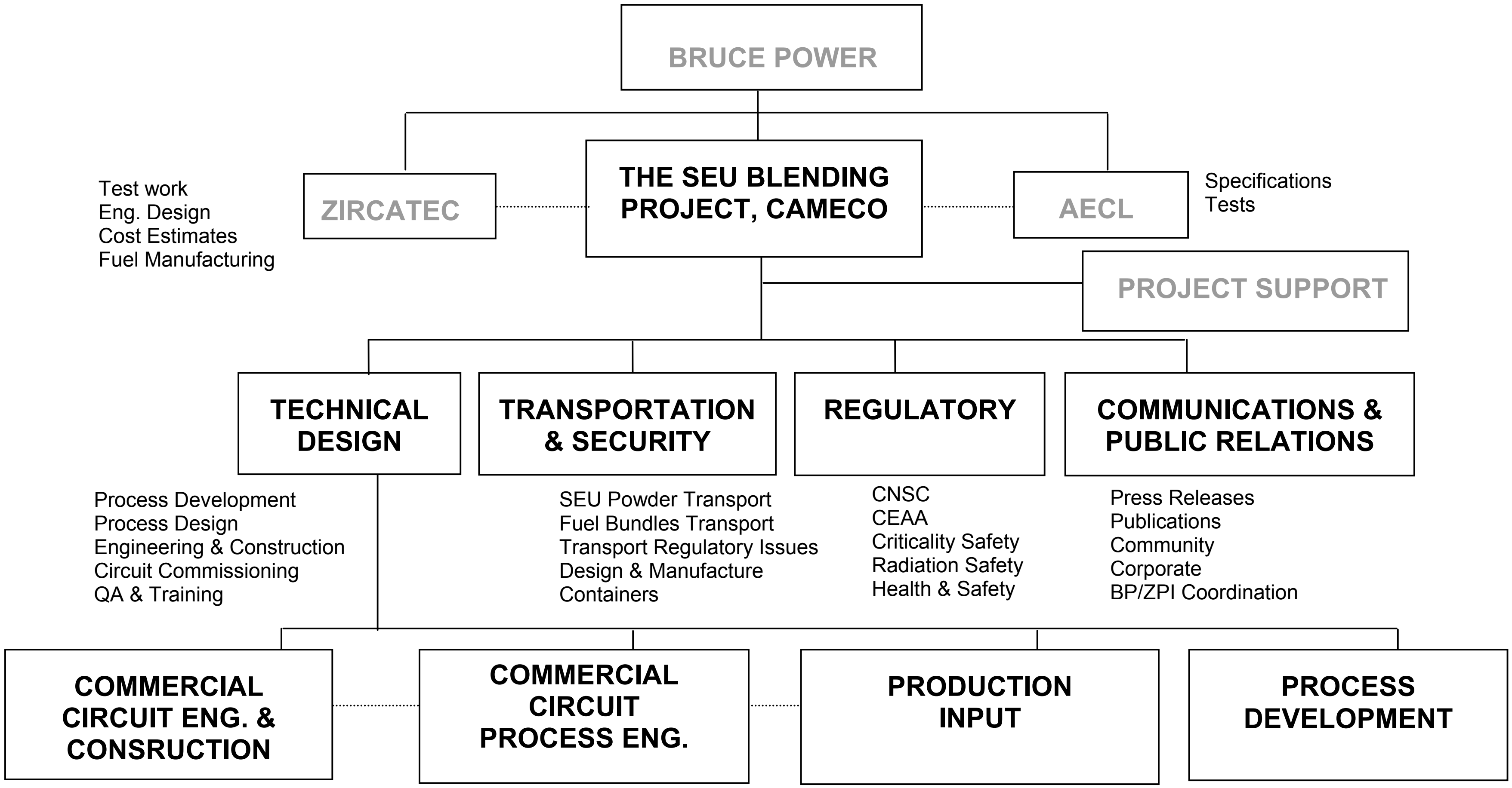

Figure 2. SEU Blending Project Organization Conceptual Design Engineering Phase

3.2.2 Cameco Project Team

During the engineering design phase, the overall project team structure remained the same however the technical design team was formed with employees being seconded on a full time bases to develop the engineering design of the process. An organization chart of the technical design team is shown in Figure 3.

3.2.3 Outcome

This phase of engineering was completed in early 2004. The information and documentation generated during this phase of the engineering formed the basis for the detailed engineering and construction phase that began in mid 2004. A comprehensive HAZOP was performed over a 3 week period and involved over 20 individuals from Cameco and consultants. Members of the HAZOP team included process operators, maintenance personnel, environmental personnel, compliance and licencing representatives, criticality safety experts, health and safety specialists and various lead discipline engineers from Cameco and the consulting engineering firm. The draft environmental assessment study report was issued to CNSC for comments. Several safety, environmental, regulatory, construction and production issues were considered during this phase of engineering.

3.3 Detailed Engineering and Construction

3.3.1 Objective

This phase of the project commenced in May 2004 with the start of detailed engineering. This phase is also referred to as the Engineering, Procurment and Construction (EPC) phase. During this phase the detailed engineering, the procurement of equipment, construction of the plant, and comissioning are being undertaken. These activities must occur within the scheduled timeline and budgetted costs to ensure an adequate supply of SEU and BDU for the Bruce New Fuel Project.

3.3.2 Project Team

The project team for the EPC phase of the project includes the base team from the previous phases, plus includes additional personnel in the technical design team for the engineering and construction phases. The organizational chart of the technical design team is illustrated in Figure 4.

3.3.3 Construction

Construction is scheduled to start in 2005 and is expected to take up to 15 months and employ up to 80 people.

3.3.4 Health and Safety

As with the previous phases of the engineering, health and safety aspects are being addressed during this phase. Criticality safety and ongoing training will continue. A detailed HAZOP review will also occur once the detailed engineering design is nearing completion prior to the start of mechanical installation and construction. Several of the safety and environmental aspects of the project are described in the following sections.

3.3.5 Key Safety Design Features

The design of the SEU Blending Facility includes features that guarantee dryness in the blending area for criticality (i.e., inadvertent nuclear chain reaction) safety control. Alternative means other than water sprinklers will be used to meet the fire code. Implementing clean plant design principles such as source dust collection and dust hoods where potential dust generation occurs will minimize emissions of dust into the plant environment.

Air monitoring for uranium dust will be conducted both indoors and at the exhaust stacks from the dust collectors. Area ventilation can also be shut off, if the allowable uranium-in-air limit is exceeded. There are no separate building heating, ventilation and air conditioning exhausts anticipated, since the airflow through the process exhausts will provide adequate building ventilation. Therefore, all exhausts from the building process areas will pass through filters.

Access to the SEU Blending Facility area will be limited. Entry to the SEU process area will be monitored through access control procedures, which permits only trained or accompanied personnel to enter the area. A separate area for the SEU production blending circuit, segregated by concrete walls and ceiling, provides a higher level of security, and will also result in better uranium accountability and the prevention of cross contamination.

Workstations are being designed to minimize physical exposure to powder products and to address ergonomic and human factor issues. Automation is being employed wherever practical in the design. To ensure cleanliness in the operations, the principles being used in the pharmaceutical industry are being adopted in the design criteria aiming for “hospital clean working environment”.

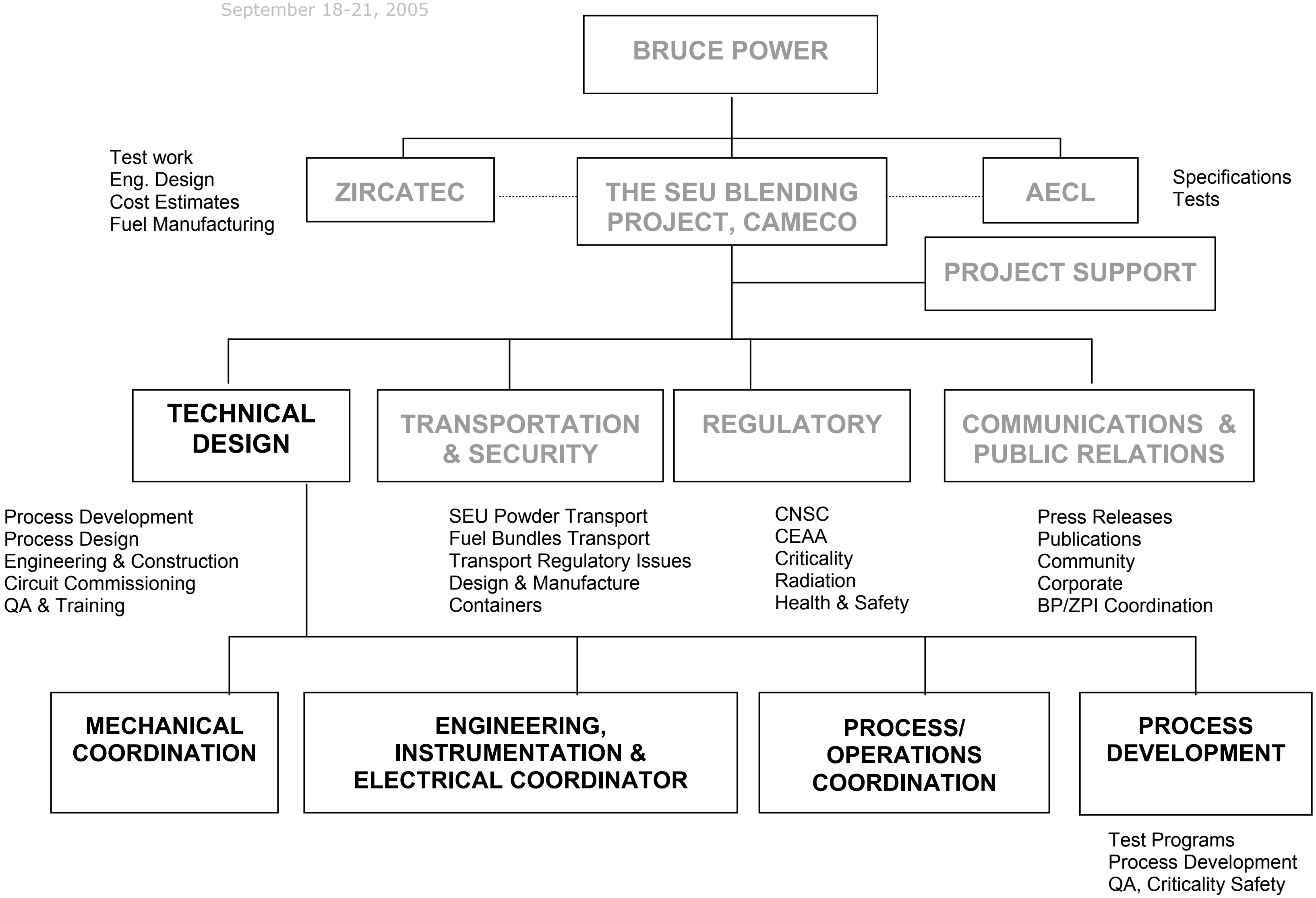

Figure 3. SEU Blending Project Organization Conceptual Design Engineering Phase

3.3.6 Regulatory Requirements

The Canadian Nuclear Safety Commission (CNSC) is the federal authority responsible for the regulation of nuclear facilities in Canada. The construction and operation of the SEU Blending Facility would be authorized by the CNSC under the Nuclear Safety and Control Act. Licensing approval from the CNSC invokes a federal Environmental Assessment (EA) under the Canadian Environmental Assessment Act (CEAA.) The CNSC has determined that a screening level assessment is required for the proposed SEU Blending Project. As of May 2004, the draft EA study report has been reviewed by the CNSC and comments have been received. The EA process is on-going and will involve further public comments on the CNSC's response, before submission to the commission for further consideration.

3.3.7 Criticality Safety for the Proposed SEU Blending Project

Changes to the existing systems at the PHCF will include the incorporation of the technical aspects of criticality safety into the design and operation of the SEU blending and SEU scrap processing circuits. These technical aspects cover the various physical parameters that ensure an inadvertent criticality event will not occur. An important principle guiding the design is called the "Double Contingency Principle", which states that the design should have sufficient factors of safety to require at least two unlikely, independent and concurrent events before a criticality is possible (ANSI/ANS 1998). In the SEU project, the double contingency principle will be implemented by controlled two or more different criticality controllable parameters or with two independent controls on one parameter. Also it was recognized that for criticality safety control that engineering controls are preferred to administrative controls.

Controllable parameters that can be used to prevent criticality are summarized by the acronym MAGIC MERV, which stands for the following:

Mass – quantity of fissile material
Absorption – neutrons absorbed rather than fission
Geometry – size and shape of vessel/container
Interaction – neutrons leaking from one vessel to another
Concentration / Density – amount of fissile material per volume
Moderation – slowing down of neutrons
Enrichment – percentage of ^{235}U in uranium
Reflection – neutrons bouncing back into a container / vessel
Volume – capacity of a container

There are two general areas of the proposed SEU plant that have different criticality safety aspects. They are the SEU blending circuit and the SEU scrap recovery circuit. Generally in the SEU blending area moderation control is employed to prevent criticality. In the scrap area, geometry control is the primary control. One common approach that has been adopted for all areas of the plant is that specific safety systems are designed to handle the maximum level of enrichment (i.e., 5% U-235) that is possible. Although the levels of enrichment in most of the plant will be considerably less than 5% U-235, this design philosophy helps to provide a high level of assurance the plant will be safe.

As the project advances to construction and operating phases, the design and review process will cover progressively more detailed information related to the criticality safety program, formal criticality safety evaluation, specific operational controls, and a comprehensive operating procedures development and training program for all the operations personnel involved.

Cameco has included criticality safety considerations into the design of the project from the very beginning. This has been accomplished by including criticality safety consultants in the design process and on-going training of PHCF staff as well as engineering design consultants. The criticality safety consultants played an important role by bringing decades of personal experience in criticality safety to the design process starting in 2001. Training will be on-going throughout the detailed engineering, construction, commissioning and operations phases of the project.

3.3.8 Environmental Impact Considerations

Minimizing the impact on the environment has been a vital aspect in the design of the SEU plant. As required by the CNSC the screening level environmental assessment study was performed on the project and in summary it was found that the project will have negligible impact on the environment. Some key aspects in the plant design included HEPA filtering of all air exhausting from process areas, no liquid effluents from the plant, and state of the art scrubbers for the removal of process fumes. As well, waste management considerations were incorporated into the plant design to allow for treatment and processing of virtually all waste streams within the facility. This includes treatment of employees' personal protective equipment (PPE), contaminated equipment and materials, and various wastes from labs and plant cleaning activities.

3.3.9 Quality Assurance Considerations

A QA team was formed in the early stages of the design to ensure that QA issues of the development work and commercial production are addressed. Draft specifications were produced for SEU and BDU powder products. SEU and BDU scrap products quality specifications were prepared for the supply of LEU and Dy_2O_3 powders, and inspection and test plans were prepared for the production of SEU and BDU for the demonstration irradiation test bundles. The QA team consists of approximately 10 members with experience in the process design, Cameco quality systems, and operations.

4.0 PROCESS DESCRIPTION

An outline of the main processing activities are illustrated in Figure 5 with a block diagram flowsheet.

4.1 LEU Receiving and Storage

It is expected that Cameco will receive commercial LEU powders at the SEU Blending Facility from several possible suppliers and at various possible enrichment levels in the range of 3% to less than 5% U-235. All LEU will be received exclusively at the new shipping/receiving area. Upon receipt, overpacks containing the LEU will be transported into the SEU production area. The overpacks will be opened, and the pails removed. The pails will be weighed to confirm the shipping weight, then after testing for moisture, will be emptied into a blending container. The blending container will be processed through a blending process, then sampled. The LEU blending container will be sized for approximately 1,500 kg of LEU, enough for one complete SEU lot. The empty LEU pails will be returned to the overpacks, and the overpacks will be returned to the supplier. The inventory of LEU will be stored in blending containers within the SEU guaranteed dry area.

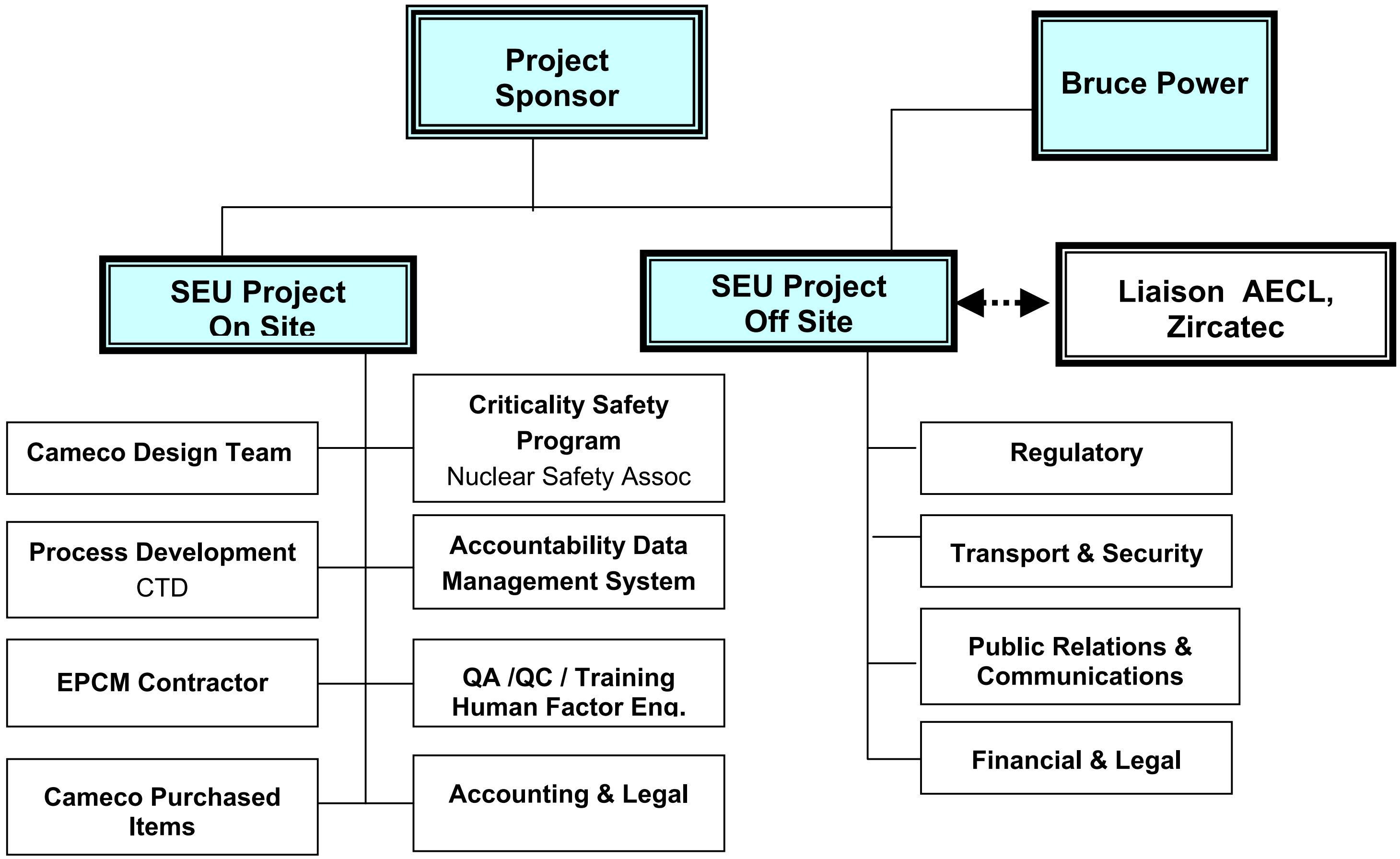

Figure 4. **SEU Blending Project Organization Detailed Engineering Phase**

4.2 SEU Blending

A complete SEU lot is considered as an NU lot (typically 8,500 kg in size), blended with an appropriate amount of LEU to achieve the desired final enrichment. Processed enriched uranium oxide scrap will also be added to the blend. Blending and storage will occur in blending containers. Each blending container will hold approximately 1,500 kg of SEU product.

When a SEU blending container is required to be filled, the NU drums will be discharged into a hopper. After testing to assure a low moisture content of the powder, the powder will be discharged into the SEU blending container. The empty NU drums will be recycled to the UO_2 plant to be refilled.

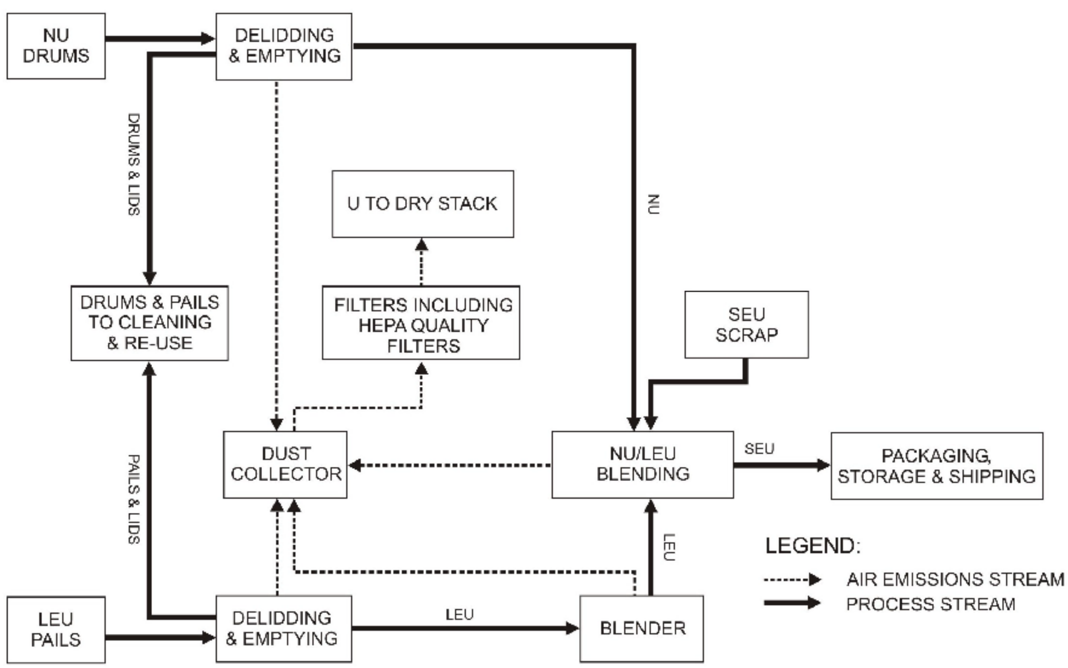

Figure 5. SEU Blending Process Flowsheet

Once the required amount of NU has been added to the blending container, the LEU can be added. The LEU will be added from a blending container with blended LEU positioned above the SEU blending container. The required amount of LEU will be metered into the SEU blending container according to the weight of NU added. Once empty, the LEU blending container will be returned to be refilled with LEU when the next shipment arrives. If required, processed scrap from the scrap treatment circuit can also be added to the SEU blending container. The processed scrap will be fed from a blending container filled in the scrap treatment area. After the required amounts of NU, LEU and refined scrap are added to the blending container, the blending process can be initiated. After the blending process is complete, the blending container will be sampled, weighed and stored while awaiting certification that the contents meet the desired product specifications.

EXAMPLES OF COMMERCIALLY AVAILABLE SEU AND LEU PACKAGES

A) BNFL 3516 Container

B) Pactec TNF-XI Container

C) Global Nuclear Fuels New Powder Container (NPC)

D) Columbiana OP-TU Container

Figure 6. Examples of commercially available SEU and LEU packages

4.2.1 Packaging, Storage and Transportation

The required inventory of SEU will be stored in blending containers. The storage areas for NU drums, LEU blending containers, and SEU blending containers are in separate areas to prevent cross contamination.

After certification of the blend, the final SEU product is packaged into reusable pails. These pails will be loaded into approved shipping overpack containers. The SEU product will be transported by truck to a fuel manufacturer. Examples of commercially available SEU and LEU packages are shown in Figure 6.

4.2.2 Feed and Product Quality Assurance

Cameco will expand the existing quality assurance (QA) program to ensure various aspects of the process conform to the specified quality for SEU powder production.

4.3 BDU Production

The BDU process requires batch blending of up to 15 wt% Dy_2O_3 with NU powder. This process is similar to the dry blending of SEU, except that there is no enriched uranium utilized. Therefore, criticality issues found in SEU blending are not a concern for BDU production. Any cross-contamination of Dy_2O_3 will be minimized by stringent standards for product containment and control.

4.3.1 Receiving and Storage

Cameco may receive Dy_2O_3 powder from more than one vendor. The Dy_2O_3 will be stored in the pails in which it was received.

Natural ceramic-grade UO_2 is supplied by the UO_2 plant from certified lots in drums and each drum contains an average of 329 kgU (377 kg UO_2). Empty drums are recycled to the UO_2 plant for reuse.

4.3.2 BDU Blending

Blending of BDU involves adding feed materials to a blending container. UO_2 drums from a certified UO_2 lot and Dy_2O_3 powder containers will be selected and one or two drums (as required) will be emptied into a feed hopper.

A process schematic is provided in Figure 7. If particle size reduction of feed Dy_2O_3 powder is required, a grinding system will be provided.

After the required amounts of NU and Dy_2O_3 are added to the blending container, the blending process can be initiated. After the blending process is complete, the blending container will be sampled, weighed and stored while awaiting certification that the contents meet the desired product specifications.

The BDU powder will be shipped in the blending container to the fuel fabricator.

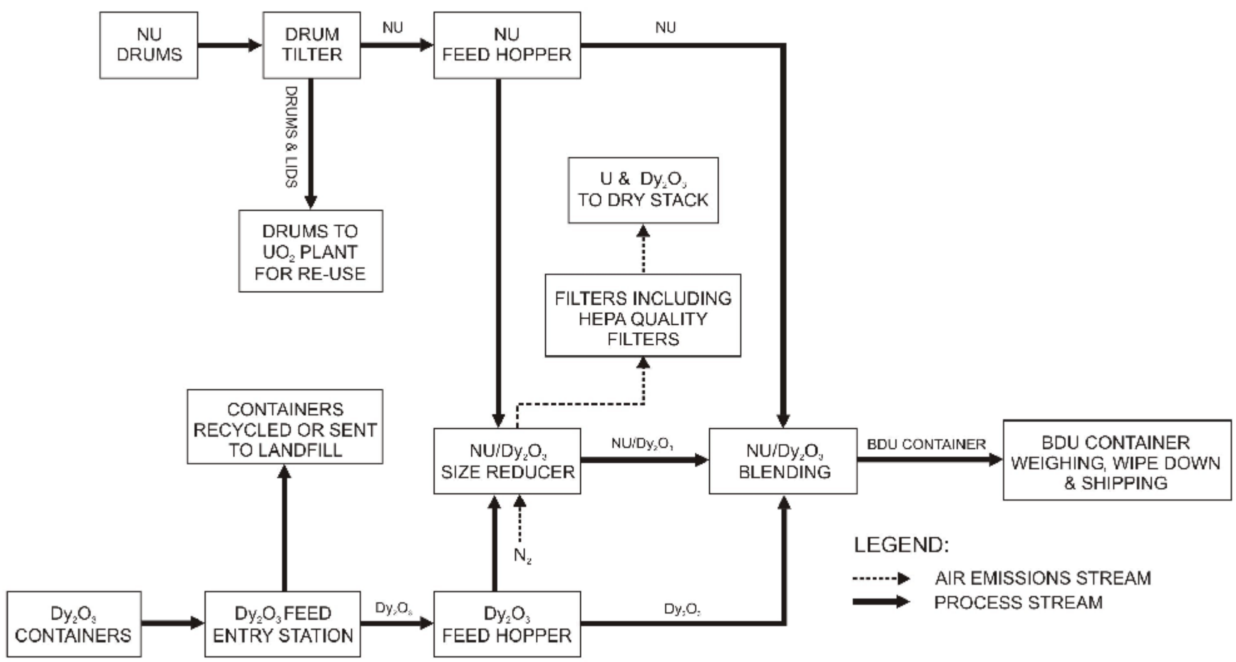

Figure 7. BDU Blending Process Flowsheet

4.3.3 Sampling and Quality Assurance

Cameco is expanding the existing approved vendor program to suppliers of Dy_2O_3 to guarantee the quality of BDU powder.

4.4 Scrap Treatment

During dry blending and pellet fabrication small quantities of scrap SEU will be generated. Scrap may consist of pellets and powder that were used for laboratory analyses, or powder from housekeeping, dust collection system and equipment maintenance that is collected by the vacuum cleaning system. Scrap will also be generated from washing of dust collector bags and filters. In addition, scrap from the fuel manufacturer will be returned to Cameco for recovery.

BDU-contaminated materials will be segregated from non-uranium/Dy_2O_3 contaminated materials. Contaminated scrap (e.g., floor sweepings and grinder sludge) will be treated through existing scrap treatment processes at the Blind River Refinery. Articles contaminated with Dy_2O_3 or BDU will be washed and the wastewater will be treated in existing facilities at PHCF. BDU scrap generated at the fuel manufacturers will be treated in the Blind River Refinery Facility without affecting the existing operations. Empty containers of Dy_2O_3 will be kept free of uranium and cleaned separately and will be returned to the supplier of Dy_2O_3 or disposed as ordinary waste. Combustible materials contaminated with BDU will be incinerated using existing facilities.

5.0 CONCLUSIONS

The SEU project was initaited to satisfy the market demand for slightly enriched uranium to be used in CANDU reactors, and maintain Cameco's position as a dominant nuclear energy fuel supplier. As well, this project will meet the required measures of success by providing a safe, healthy and rewarding workplace, a clean environment, supportive communities and solid financial performance---all reflected in a growing return to shareholders of Cameco benefit the stake holders on 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 PHCF, Materials Handling/Transportation PHCF, Public Relations/Communications, PHCF and Corporate Office, Health Physics of Health, Safety and Environment Division, Corporate Development and Marketing Division.