Technical Reports

Safety Analysis Report - Public Summary

Cameco Fuel Manufacturing

Safety Analysis Report

Cameco Corporation's (Cameco) Cameco Fuel Manufacturing (CFM) facility holds fuel fabrication licence from the Canadian Nuclear Safety Commission (CNSC) to fabricate fuel bundles for use as fuel for nuclear generating stations. CFM is located at 200 Dorset Street East in the Municipality of Port Hope (MPH).

The protection of the environment and health and safety of persons is a fundamental principle of the *Nuclear Safety and Control Act*, its regulations and the regulatory approval process. A requirement of that licence is that CFM must regularly review and update a safety analysis report, which identifies potential hazards at the operation and outlines how the facility will prevent and mitigate their potential impact on people and the environment.

The detailed descriptions of process equipment and controls as well as other information contained within the Safety Analysis Report for Cameco Fuel Manufacturing, Inc. (Port Hope Facility) is prescribed information, controlled nuclear information pursuant to the *Nuclear Non-proliferation Import and Export Control Regulations* or information that is exempted from disclosure under the *Access to Information Act*, and therefore cannot be made publicly available. This summary provides an overview of the methodology and results of the assessments described in the Safety Analysis Report (SAR), which was reviewed and accepted by CNSC Staff in 2021.

The International Atomic Energy Agency (IAEA) SSR-4 Safety of Fuel Cycle Facilities was used as guidance for the SAR methodology and analysis of supporting documentation to ensure a comprehensive analysis of CFM operations.

The SAR is periodically reviewed, on a frequency not to exceed every five years, which includes:

- assessing incidents that have occurred at the facility against the report to confirm the response of safety systems
- assessing all design changes, including those initiated as a result of an incident or accident
- assessing the results of supporting studies and reports
- reviewing the credible accident scenarios and predictive modelling

Methodology

Hazard risk assessments and safety analyses are now the cornerstone of process safety management throughout the world. This is a widely accepted method and practice used by industry and regulators to assess the risk and potential impact from plant operations.

A safety analysis of CFM was most recently completed in 2021 using the "What-If?" analysis technique. This was a systematic review that identified and analyzed potential causes and consequences of facility hazards focusing on equipment, instrumentation, utilities, human actions and external factors that might impact the process. Incident scenarios and protective barriers available to prevent or mitigate an uncontrolled release or other undesirable result are documented in the SAR.

The study did not bring to light any previously unidentified safety concerns of significance. A structured design control system is maintained to review and assess current and future operational changes. Changes are reviewed prior to making any plant modifications that may affect the safety case. The SAR is periodically updated to include any facility changes completed since the last revision to the report.

Additional studies and reports support the study in establishing a systematic review of operations including a fire hazard analysis, environmental risk assessment, assessment of public dose, environmental aspects, evaluation of external initiating events, external event analysis report, and air dispersion modelling.

Defence in Depth

CFM's safety systems are built on the Defence-in-Depth Multiple barrier concept. It is intended to eliminate or minimize the potential of radiological, chemical or other physical hazards to facility personnel, the environment and the general public. This is accomplished through implementation of safety features and systems which can prevent hazards and/or ensure appropriate protection in the event that the prevention measure falters. The systems also allows the failure to be detected and compensated for or corrected, and considers organizational and human performance. Many of these features and systems are independent and redundant. The defence-in depth model depicts how the emergency planning process begins long before activation of the site and community emergency plans. Safety systems comprise many barriers from design through to containment systems that are implemented before emergency response as illustrated in Figure 1.

The following Administrative Barriers apply to all licensed activity at CFM to maintain control:

- Management System
  - o Change management
  - o Preventative maintenance
- Operator training and qualification
- Additional operating controls
  - o Contamination control procedures
  - o Respiratory protection
  - o Personal protective equipment
- Monitoring Programs
  - o Environmental protection program
  - o Radiation protection program
  - o Dosimetry program
- Emergency Response Plan and Fire Safety Program

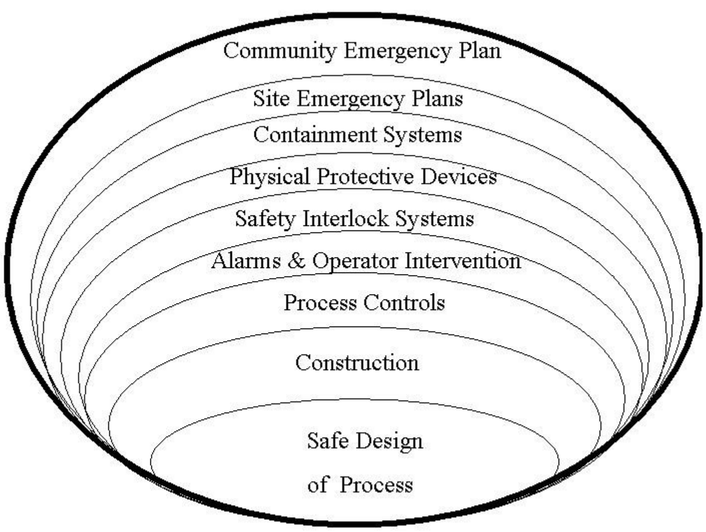


Figure 1

Overview of the Safety Analysis for Cameco Fuel Manufacturing

Safety Analysis – Operations

At the CFM facility, uranium dioxide (UO_2) is delivered in drums. The UO_2 is transferred to processing vessels where it is pre-compacted, granulated and blended in preparation for pelleting. The conditioned UO_2 powder is pressed within a die to produce a cylindrical shaped "green" pellet.

Green pellets are passed through a sintering furnace with a hydrogen atmosphere in which the uranium dioxide is reduced to convert the pellet's physical form to a hard, high-density, non-friable ceramic. These sintered pellets are then ground to the specific dimensions required for the fuel element assembly. Stacks of pellets are loaded into a fuel subassembly tube and hermetically sealed within the fuel tube by welded end caps.

The final process involves assembling individual elements into a bundle assembly where zircaloy end plates are resistance welded onto the element ends to hold them in the required configuration.

Safety Analysis – Initiating Events

As part of the SAR, natural initiating events (ice storm, earth quake, tornado, forest fire) and man-made initiating events (fire, explosion, structural collapse, flood, train derailment, airplane crash) which could result in a significant accident were assessed. These events were assessed to have a frequency of less than 10^{-6}/yr or 1 in a million.

Most events identified in the SAR were categorized as operations/equipment issues or process upset conditions expected in normal operations. A loss of containment of uranium dioxide powder is the expected upset condition, which could result in inhalation/ingestion of uranium and radiation exposure for workers while mitigating the event or a limited release to the natural environment.

The SAR defines the structures, systems and components (SSC) critical to maintaining safe operation of the facility. For CFM, the containment of uranium and other hazardous materials is the primary means of protecting workers and the public from radiation exposure. Equipment enclosures and dust collection are thereby the SSC that are required to maintain a safe state for the facility. Preventative maintenance ensures that these systems remain operable and routine monitoring at the points of discharge from these systems confirms that they remain operational and effective.

Uranium Dioxide Receipt and Storage

UO_2 powder is shipped by truck to CFM where the drums are unloaded and stored. The drums are placed onto a roller conveyor where the drums and bag liners are opened in preparation for movement to the next area in the process. The following safety systems are used in the UO_2 powder receipt area to ensure that workers, the public and the environment are protected.

Engineered Barriers:

- Powder handled in engineered enclosures
- Localized extraction lines
- Separation of work areas
- Radiation shielding
- Fire protection systems
- Leak detection systems
  - Uranium in air monitors

Additional Administrative Barriers:

- Limited number of drums are unsealed at any time
- UO_2 powder inventory is typically just-in-time delivery
- Operators wear designated personal protective equipment
- Prompt clean-up of spills with HEPA vacuum

Powder Pre-Compaction, Granulation and Blending

In this preparatory stage, with local extraction, the UO_2 is transferred to a secondary container for further processing. New UO_2 powder may be combined with reprocessed material before it is pre- compacted, granulated and blended using conventional powder processing techniques.

The following safety systems are used for powder preparation activities to ensure that workers, the public and the environment are protected.

Engineered Barriers:

- Powder handled in engineered enclosures
- Localized extraction lines
- Interlocks on extraction and machine guards
- Leak detection systems
  - Uranium in air monitors
- Separation of work areas
- Radiation shielding
- Mechanized lifting and moving devices
- Machine guarding
- Emergency Stops
- Fire Protection Systems

Additional Administrative Barriers:

- System is designed to minimize UO_2 powder in the process
- Operators wear designated personal protective equipment
- Prompt clean-up of spills with HEPA vacuum

Pellet Pressing

Once conditioned, the powder is moved in cone shaped vessels from the powder preparation area to the pressing area.
In the pressing area, conventional tablet presses are used to compress the powder within a die cavity to produce cylindrical pellets of relatively low density known as green pellets. The following safety systems are used in the pellet press area to ensure that workers, the public and the environment are protected.

Engineered Barriers:

- Localized extraction lines
- Leak detection systems
  - Uranium in air monitors
- Radiation shielding
- Mechanized lifting and moving devices
- Machine guarding
- Emergency Stops
- Interlocks on extraction and machine guards
- Fire Protection Systems

Additional Administrative Barriers:

- System is designed to minimize UO_2 powder in the process
- Operators wear designated personal protective equipment
- Prompt clean-up of spills with HEPA vacuum

Pellet Grinding

Sintered pellets are ground to the required dimensions for diameter and surface finish. The following safety systems are used in the pellet grinding area to ensure that workers, the public and the environment are protected.

Engineered Barriers:

- Pellets handled in enclosed areas
- Dust and mist collection systems
- Leak detection systems
    - Uranium in air monitors
- Radiation shielding
- Machine guarding
- Emergency Stops
- Interlocks on extraction and machine guards
- Fire Protection Systems

Pellet Sintering

The green pellets are passed through a sintering furnace in a hydrogen atmosphere to reduce the UO_2 to stoichiometric UO_2. This converts the pellet's physical form to a hard, high-density, non- friable ceramic. Once in this form, the primary hazard is radiological as the likelihood of an exposure to workers through ingestion/inhalation is significantly reduced. The following safety systems are used in the sintering area to ensure that workers, the public and the environment are protected.

Engineered Barriers:

- Dust and fume collection system
- Leak detection systems
    - Uranium in air monitors
    - Hydrogen monitors
- Radiation shielding
- Machine guarding
- Interlocks on furnace controls
- Emergency Stops
- Fire Protection Systems

Additional Administrative Barriers:

- Operators wear designated personal protective equipment

Pellet Washing and Drying

The pellets are washed using de-mineralized water and dried to remove the fines and debris created during the grinding process. The following safety systems are used in the sintering area to ensure that workers, the public and the environment are protected.

Engineered Barriers:

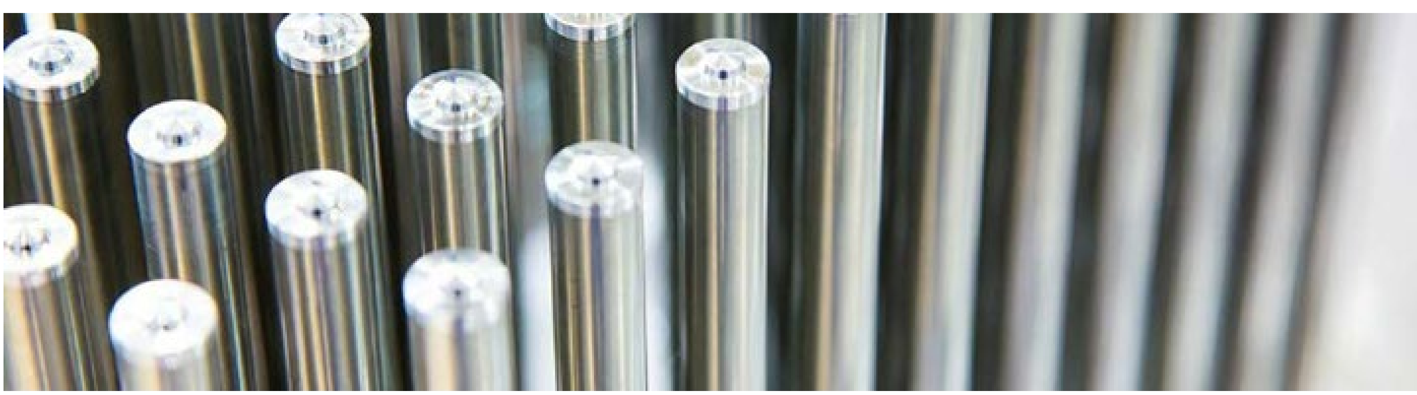
- Dust and mist collection systems
- Leak detection systems
    - o Uranium in air monitors
- Fire Protection Systems

Pellet Stacking

The pellets are placed end-to-end to produce a fuel stack and the stack length is verified to ensure they are within the required tolerances. The following safety systems are used in the sintering area to ensure that workers, the public and the environment are protected.

Engineering Barriers:

- Pellets handled in enclosed areas
- Robotic handling of uranium
- Leak detection systems
    - o Uranium in air monitors
- Radiation shielding
- Fire Protection Systems



Bundle Assembly

Fuel elements are made by loading fuel stacks into zircaloy tubes and welding endcaps on the ends. These elements are placed in the required configuration and then assembled into fuel bundles by welding end plates using a robotic system. Quality verifications are performed during this process. The following safety systems are used in the sintering area to ensure that workers, the public and the environment are protected.

Engineered Barriers:

- Pellets handled in enclosed areas
- Robotic handling of uranium
- Dust and fume collection lines
- Radiation shielding
- Fire Protection Systems for metal fires

Bundle Inspection and Packaging

Completed bundles are inspected via a series of non-destructive visual and dimensional tests. Bundles are then packed into shipping containers and placed into storage until shipped to customers. . The following safety systems are used in the sintering area to ensure that workers, the public and the environment are protected.

Engineering Barriers:

- Dust collection lines
- Shielded storage
- Mechanized lifting and moving devices
- Fire Protection Systems

Storage

CFM stores fuel bundles and waste materials in designated areas at the Port Hope Facility. The following safety systems are used in the sintering area to ensure that workers, the public and the environment are protected.

Engineering Barriers:

- Radiation shielding
- Mechanized lifting and moving devices
- Fire Protection Systems

Additional Administrative Barriers:

- Radiation Monitoring Programs

Waste Treatment

The waste treatment areas process material from different stages of the production circuit for internal or external uranium recovery. Waste treatment also involves preliminary handling of materials managed through the site waste management program, including waste water treatment and equipment cleaning. The following safety systems are used in the waste treatment area to ensure that workers, the public and the environment are protected.

Engineering Barriers:

- Dust collection lines
- Leak detection systems
    - Uranium in air monitors
- Radiation shielding
- Fire Protection Systems

Additional Administrative Barriers:

- Operators wear designated personal protective equipment

Groundwater Treatment

The groundwater treatment facility is used to remove historically deposited trichloroethylene (TCE) from groundwater at the facility. The following safety systems are used in the sintering area to ensure that workers, the public and the environment are protected.

Engineering Barriers:

- Access is limited to qualified personnel

Liquid Hydrogen

The liquid hydrogen supply and storage provides gaseous hydrogen to the UO_2 sintering furnaces. The operation and maintenance of the system is completed by the third party supplier, the distribution system is maintained by CFM. The following safety systems are used in this area to ensure that workers, the public and the environment are protected.

Engineering Barriers:

- Facility designed and constructed to NFPA 50B: Standard for Liquified Hydrogen Systems at Consumer Sites
    - Pressure control, relief lines, vent stack
    - Flow control devices
    - Purges on the regulators and distribution lines
    - Backflow prevention
- Access is limited by fencing
- Fire Protection Systems
- Emergency systems and interlocks

Administrative Barriers:

- Qualified supplier
- Monitoring Programs
    - Biannual third party inspections
- Operational restrictions
    - Authorized personnel
    - Exclusion zone

Additional Assessment for Liquid Hydrogen

CFM has extensive operational experience in handling liquid hydrogen at its facility. Nevertheless, Cameco periodically commissions safety assessments of bulk storage of chemicals. For liquid hydrogen, the most recent assessment was completed in 2016. This work compiled relevant historical incidents with liquid hydrogen that were relevant to Cameco's operations and reviewed rupture disk failures on storage tanks and tube trailers, BLEVE incidents, road transportation incidents and liquefaction and storage incidents. It concluded that based on the reported evidence, despite occasional rupture disk failures and operator errors leading to occasional gas venting and fires, the overall safety record of LH_2 delivery transfer and storage is very strong.

Events like BLEVE and fireballs, typical for cryogenic hydrocarbons, appear to be not very typical for liquid hydrogen and mostly come from the academic / research assessments. In reality, such phenomena are not possible: even after a tank rupture, most of the hydrogen is still in liquid form, the produced gas is very cold and concentrated and, thus, cannot all ignite at once. In this case, a relatively small flash fire is a much more realistic scenario.

Safety Analysis and Planning for Emergencies

Assessment of Potential Releases for Emergency Planning

The Safety Analysis Report evaluated the major processes at CFM to identify potential process upsets and credible accident scenarios that could result in releases to the environment or dose to a member of the public. The credible scenarios assessed include a fire in the fabrication area resulting in a release of UO2 powder from the plant and a rupture of the hydrogen storage system

Accidental Release Scenario – Hydrogen Station

Three realistic hydrogen accident scenarios were modelled in this assessment with the most extreme scenario (a hose rupture during transfer of liquid hydrogen) having the potential to cause damage to the hydrogen storage unit and associated piping, and if there were individuals within the fenced exclusion zone at the time of the event, potential critical injury to those workers. No offsite impacts were noted. The engineered and administrative controls in place at CFM, reduce the likelihood of this type of event and mitigate the potential consequences from an incident involving liquid hydrogen.

Accidental Release Scenario – Fire

For the fire scenario, the fire hazard analysis concluded that the protection measures and systems in place at CFM are adequate to mitigate and protect the public and the environment for the worst-case scenario. The credible release scenario was based on a gas explosion and fire in the baghouse resulting in the release of 40 kg of uranium over a 30-minute period. The release was modelled using software designed to evaluate the concentration of uranium in proximity to the facility. This work determined that under all scenarios assessed, the 1-hour UO_2 maximum concentration is well below the applicable emergency guidelines of 10 mg/m3 at which level nearly all individuals could be exposed for up to 60 minutes without experiencing or developing irreversible or other serious health effects or symptoms which could impair an individual's ability to take protective action. This type of release would be easily reduced by implementing emergency response protocols. It should be noted that a release of this magnitude has never occurred at CFM.

Results from air dispersion modelling exercises such as this are used to assist CFM in prioritizing its efforts to further reduce the potential for and potential impact of a release. Emergency response planning and continual improvement projects may include the improved detection of and/or response time to a release or engineered controls to prevent or mitigate a release.

Emergency Planning

Emergency planning is required for responding to hazards, actual or potential, that are identified in the Safety Analysis Report. Depending on type and magnitude of an incident, the site may activate any or all of the following response organizations for the protection of human health, the environment and property:

- Emergency Response Organization;
- Local Crisis Management Team;
- Corporate Crisis Management Team; and,
- Crisis Assistance Team (Transportation events).

These organizations include personnel from all levels of the operations and support departments. In the event of an emergency, personnel will leave their normal assigned duties and assume their role in the appropriate response organization.

Emergency preparedness and response is broken down into two components: a planning function and a response function. Planning is responsible for the development and maintenance of the emergency planning and control program. This includes the preparation and periodic review of documentation, ensuring that the program meets regulatory and internal Cameco requirements, periodic testing of the procedures, personnel and equipment to ensure that the facility is in a state of readiness. The response function is initiated only in the event of an actual or potential emergency.

One aspect of emergency planning is a component that ensures that members of the public are kept informed of developments in the event of an emergency at CFM with the potential for off-site impacts. The designated public information officer is responsible for liaising with the media and providing necessary information to the public to ensure that the impact of the emergency on the public is minimized.

In the event that urgent information needs to be communicated to the public, Cameco will request that the Municipality activate the rapid notification system, which automatically delivers a pre-recorded message to residents in the Municipality of Port Hope.

Conclusion

Based on this report, Cameco believes that the risk to the public and the environment arising from the unplanned release of hazardous materials stored, processed and transported to and from CFM has been mitigated. The current safety systems, procedural controls and abatement equipment in place mitigate risk effectively. Cameco is committed to ongoing improvement to minimize the risk to the public and to the environment in keeping with the As Low As Reasonably Achievable (ALARA) principal.