Used Fuel Packing Plant for CANDU Fuel

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Abstract

Large forgings have been selected to containerize Light Water Reactor used nuclear fuel. CANDU fuel, which is significantly smaller in size, allows novel approaches for containerization. For example, by utilizing commercially available extruded ASME pipe a conceptual design of a Used Fuel Packing Plant for containerization of used CANDU fuel in a long lived metallic container has been developed. The design adopts a modular approach with multiple independent work cells to transfer and containerize the used fuel. Based on current technologies and concepts from proven industrial systems, the Used Fuel Packing Plant can assemble twelve used fuel containers per day considering conservative levels of process availability.

1. Introduction

The Nuclear Waste Management Organization (NWMO) was established in 2002 by Ontario Power Generation Inc., Hydro-Québec and New Brunswick Power Corporation in accordance with the *Nuclear Fuel Waste Act (NFWA)* to develop and implement a plan for the long-term management of Canada's used nuclear fuel. On June 14, 2007, the Government of Canada selected the NWMO's recommendation for Adaptive Phased Management (APM). APM moves towards a goal that Canadians themselves identified: safe and secure long-term containment and isolation of used nuclear fuel produced in Canada, with flexibility for future generations to act in their own best interests. The NWMO now has the mandate to implement the recommendation.

The NWMO is in the conceptual design phase of the project and is validating a number of conceptual design options to prepare for implementation in the coming decades. Existing technologies adapted for the unique demands of containment and isolation are being demonstrated to verify conformance to performance requirements.

2. Technology

The NWMO is advancing the APM program based on implementation of a Deep Geological Repository (DGR). Used nuclear fuel is a radiological hazard for millennia. Over time, the products of nuclear fission decay and eventually achieve the radioactivity of natural uranium ore as extracted in uranium mines. During decay, it is important to keep the fuel contained and isolated from the surrounding environment.

The used fuel will be consolidated and packaged into a metallic container. The container provides a containment boundary around the used fuel. The fuel packaging process occurs in the Used Fuel Packing Plant (UFPP).

After the used fuel is packaged in the Used Fuel Container (UFC), the UFC is further embedded in a thick layer of highly compacted bentonite. This assembly process occurs in the UFPP.

The used fuel containers packed in bentonite are placed in excavated rooms at a reference depth of approximately 500 metres underground. The rooms are sealed from the main access tunnels with engineered bulkhead seals, bentonite in the access tunnels and ultimately shaft seals.

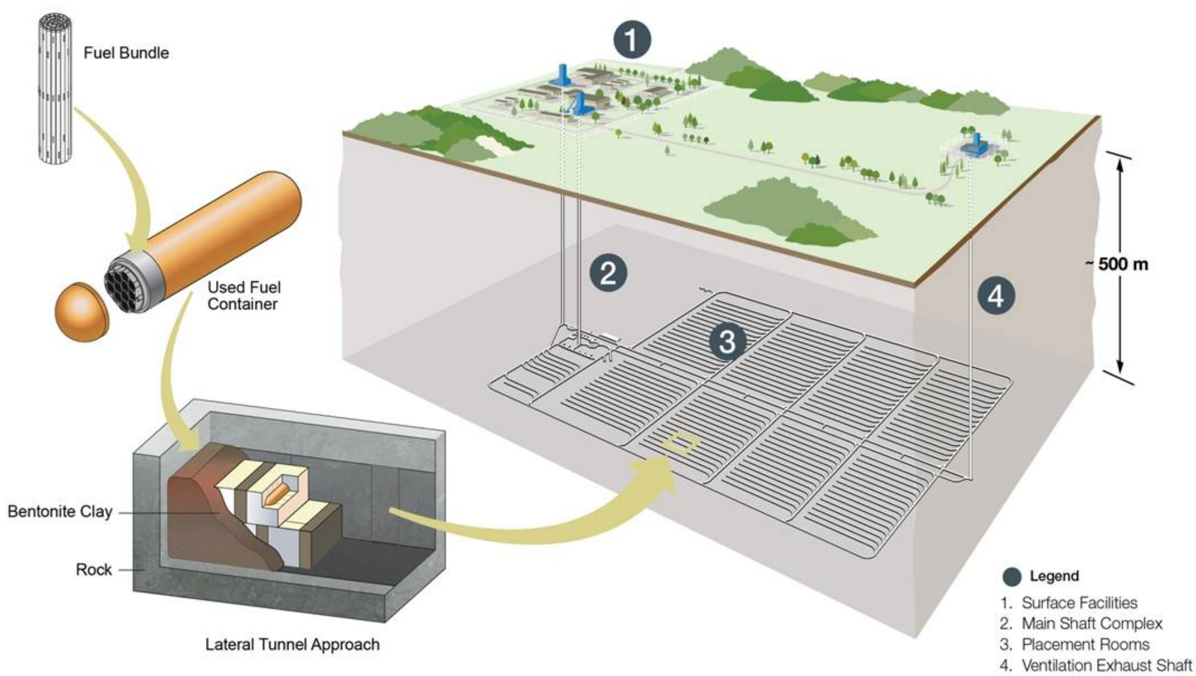


Figure 1: Mark II APM Concept

2.1 Used Fuel Container Description

The UFC is the primary engineered barrier used for containment of the used fuel. In the Mark II design, each UFC, measuring approximately 2.5 metres in length and 0.56 metres in diameter, can accommodate 48 used fuel bundles. The bundles are arranged in four layers of twelve bundles each. It is constructed of ASME SA 106 Grade C extruded steel pipe and spherical steel heads. The used fuel container body (lower assembly) is pre-assembled by welding the lower head to the pipe followed by application of the copper corrosion barrier to the external surface. The upper head is also copper coated. The weld area (closure zone) of the upper head and lower assembly are left uncoated to permit the final closure weld. Following welding, the closure zone is copper coated.

The two components will be delivered matched to the Used Fuel Packing Plant (UFPP). At the UFPP, the container is prepared for assembly, loaded with fuel, final assembled, inspected and prepared for transfer to the bentonite assembly cell.

Figure 2: Mark II Used Fuel Container

2.2 Highly Compacted Bentonite

Highly compacted bentonite blocks are fabricated in a sealing material compaction plant and supplied to the UFPP for assembly around the complete used fuel container. The UFC is placed in the bottom block. The second block is lowered onto the UFC providing a rectangular assembly ready for transfer to the repository emplacement room.

2.3 Used Fuel Container Assembly Process

The UFC assembly processes are based on existing technologies adapted by the NWMO. Working with several external organizations, a closure weld process, copper electro-deposition process (factory supplied components) and copper cold spray process have been developed for the final assembly processes of the UFC.

The quantity of used fuel that would be processed through the UFPP is assumed to be 120,000 used fuel bundles per year. This requires approximately twelve UFCs per day to be processed through the UFPP. Processing approximately six hundred CANDU bundles per day and packaging them into twelve used fuel containers requires careful design considerations.

The NWMO engaged ATS Automation to develop a conceptual design for a UFPP that could be advanced further with a high level of construction and operational confidence based on these selected processes.

3. ATS Study

The NWMO contracted ATS Automation to establish the process requirements and develop a conceptual design for a Used Fuel Packing Plant (UFPP) capable of achieving the required fuel transfer and UFC assembly rates.

3.1 Design Basis and Reference Plant Design

The design basis for the NWMO UFPP is a modification to a similar packing strategy and plant design as developed by SKB [1]. This reference plant design serves as a basis for the development of a refined, CANDU fuel focused UFPP design.

The smaller UFC invokes a couple of UFPP changes, namely:

1. UFC Throughput: Smaller capacity UFC requires an increase in UFPP container production output by almost an order of magnitude.
2. Container Assembly Processes: The smaller container requires different assembly processes.

3.1.1 UFC Throughput

Prior to adopting the 48 bundle Mark II UFC, the NWMO's reference UFC had a capacity of 360 used fuel bundles requiring 1.5 UFCs per day average production. The UFC was approximately 1.1 metres in diameter and 4.8 metres in length. This UFC permitted low assembly rates and were reflected in a plant design structured toward serial manual operation and sequencing. This UFPP does not require redundancy. Due to the low UFC output, only one or two containers are in process at any given time.

In contrast, with a smaller UFC, parallel processing of UFCs must be implemented to achieve the required throughput. Fuel handling machines will operate in parallel, loading multiple containers at a time. Each line is isolated from the other to ensure redundancy.

Further downstream, the number of processing stations would also need to be increased. In order to process the 12 UFCs per day, a takt time of 64 minutes is required assuming 16 hours of operation at 80% availability. The time to complete welding operations, copper application and annealing operations alone exceed this limit. Thus there is a need for multiple work cells to be used in parallel to achieve the required production rates.

3.1.2 Processing Effects

The smaller UFC utilizes different assembly processes to provide a corrosion resistant containment boundary. A closure weld and copper application over the weld area are required. Furthermore, to ensure the quality of the deposited copper layer, a post application NDE process is required.

Lastly, the copper application process also requires pre and post deposition processes such as surface preparation, machining and annealing processes which will result in additional work stations. Independent parallel processing operations are required for each UFC once assembly has been started.

3.1.3 Discussion

The throughput design requirement imposes a number of design philosophy changes, including:

1. Automated material handling: Conventional industrial automation handling methods can be employed. This will allow for improvements in production cycle time as well as reduce the opportunity for faults which may arise in heavy equipment handling systems.
2. Redundancy: It becomes necessary to have multiple redundant operating systems which will increase the production potential and failure immunity of the plant.
3. Fault Tolerance: Having a production target of 12 UFCs per day allows the system to maintain higher efficiencies when a failure occurs in comparison to a plant which only produces 1-2 containers per day. For example; 9 of a target 12 UFCs may be produced when a fault occurs which stops production in a single cell. The same fault in the reference case could prevent 100% of the daily production output.

3.2 Design Philosophy in Generating Concept

To develop a CANDU specific UFPP, aspects of the reference style plant are incorporated where appropriate, while new methodologies and designs are used to implement the aforementioned advantages in having a CANDU specific UFPP.

The generation of the initial UFPP concept focused on overall plant design strategies and their effects on modularity, redundancy, productivity, maintainability and rework. Possibilities included automotive type production line strategies, modular cell based manufacturing, lean cell / manual production.

Furthermore, to develop a more complete plant concept, a detailed design effort was adopted for some of the key areas and functions within the plant, including: Fuel Handling Methods, UFC Handling, UFC Shielding, Contamination Control, UFC Transport and UFC Processing.

3.2.1 Plant Design

For the overall plant design, a modular, cell based design approach was used, where function group specific work cells were implemented in multiples as needed to achieve the required production rates. The Fuel Loading Cells will input empty UFCs and output loaded UFCs. Loaded UFCs will be input into the Welding Cells and be output as Welded UFCs. The Welded UFCs will be input into the Copper Application Cells and output as Copper Coated UFCs and sent on to UFC dispatch.

UFCs will be transferred between cells using the common Intra-plant Transfer Hall at four different production stages (empty UFC, loaded UFC, welded UFC, and copper coated UFC). The UFCs will be transferred sequentially to and from each type of work cell to perform the subsequent operations. A number of each type of work cell will be available so multiple UFCs can undergo the same process in parallel.

Using a modular cell based approach provides a high level of redundancy and fault tolerance. Furthermore, the system provides a high degree of scalability. It is estimated that three (3) fuel loading cells, three (3) UFC welding cells and six (6) copper application cells will be required to meet the throughput requirements.

3.2.2 Fuel Handling

For the Fuel Handling process in the UFPP, the concept will use redundant and isolated systems for fuel handling. Based on required production rates, this method uses three independent fuel handling cells where each system would have isolation features in place to separate areas with a high probability of contamination from areas of lower risk. Furthermore, to provide improved reliability and system maintainability, the handling machinery will be isolated from the fuel.

3.2.3 UFC Handling

UFCs will be stored, transferred and processed while in the horizontal orientation. This method aligns with the preferred UFC orientation for all major assembly or processing steps, eliminating the need for special tilt tooling. The UFC will be shielded at all times, either in hot cells or within a shielded flask. The processes have been engineered for back out provisions in the event of upset conditions.

3.2.4 Contamination Control

A zoned approach will be used for contamination control within the plant. The different production areas of the plant will be isolated from one another using conventional control techniques such as airlocks and active ventilation. Having a reliable contamination control strategy is important to ensure long term reliable operation of the UFPP.

3.2.5 UFC Transport

It is expected that multiple transfer systems will be required within the UFPP. An Automated Guided Vehicle (AGV) system will be used for UFC handling. The AGV system will transfer the UFC in shielded flasks from area to area within the plant. The use of the AGV system provides a highly flexible platform which allows for modification or optimization of UFC routing.

3.2.6 UFC Processing

UFC processing work (assembly, welding, inspection, etc.) will be conducted in small shielded 'hot cells' processing one UFC at a time. This approach provides system level fault tolerance in case of a process or equipment failure in a single work cell. Furthermore, this methodology facilitates efficient expansion and or refurbishments of works cells without interrupting all plant operations.

3.2.7 Rework

Both offline and online rework systems will be used. The UFC Weld Cell and Copper Application Cell will have the capability to re-work minor defects in-situ. This approach would minimize the impact of rework on the overall production rates due to the high level of redundancy afforded by the design.

When specialized equipment may be required for rework, it may be necessary to perform offline rework. The system will have the ability to move a UFC from a processing cell into an active maintenance cell for rework. Defective UFCs that can't be repaired shall be defueled in the fuel module handling cells and transferred to the active maintenance shop where they would be scrapped.

4. Overview of Proposed Concept

Figures 3 and 5 provide an overview of the conceptual design for the UFPP. The isometric layout illustrates and identifies the different functional areas within the plant. The plant measures approximately 88 x 254 metres and includes 12 UFC processing cells.

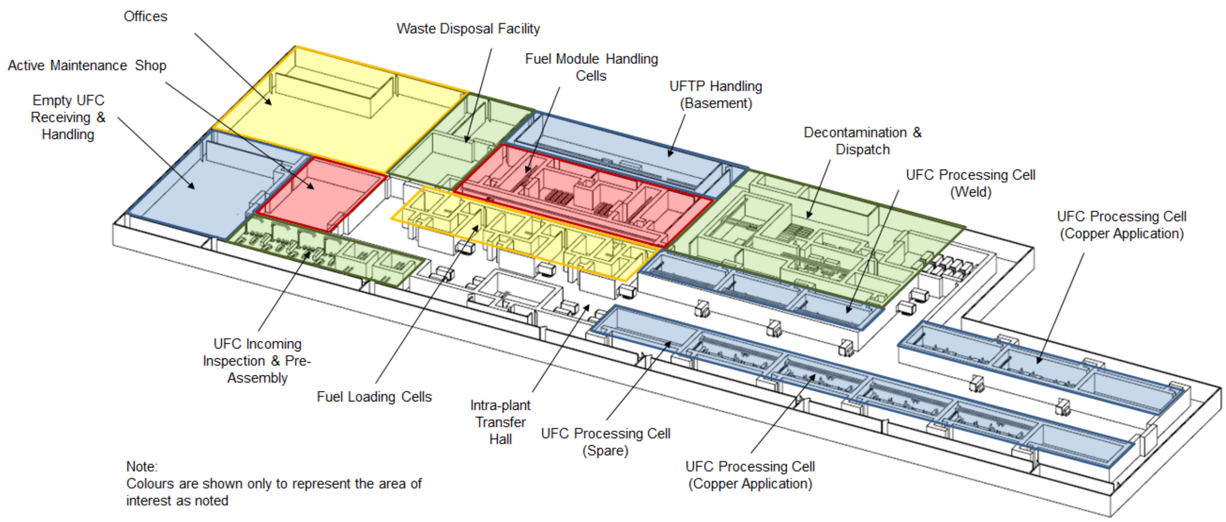


Figure 3: Plant Layout Overview

A refined UFPP process flow map is illustrated in Figure 4 where the different functional areas of the plant are overlaid with the expected zoning.

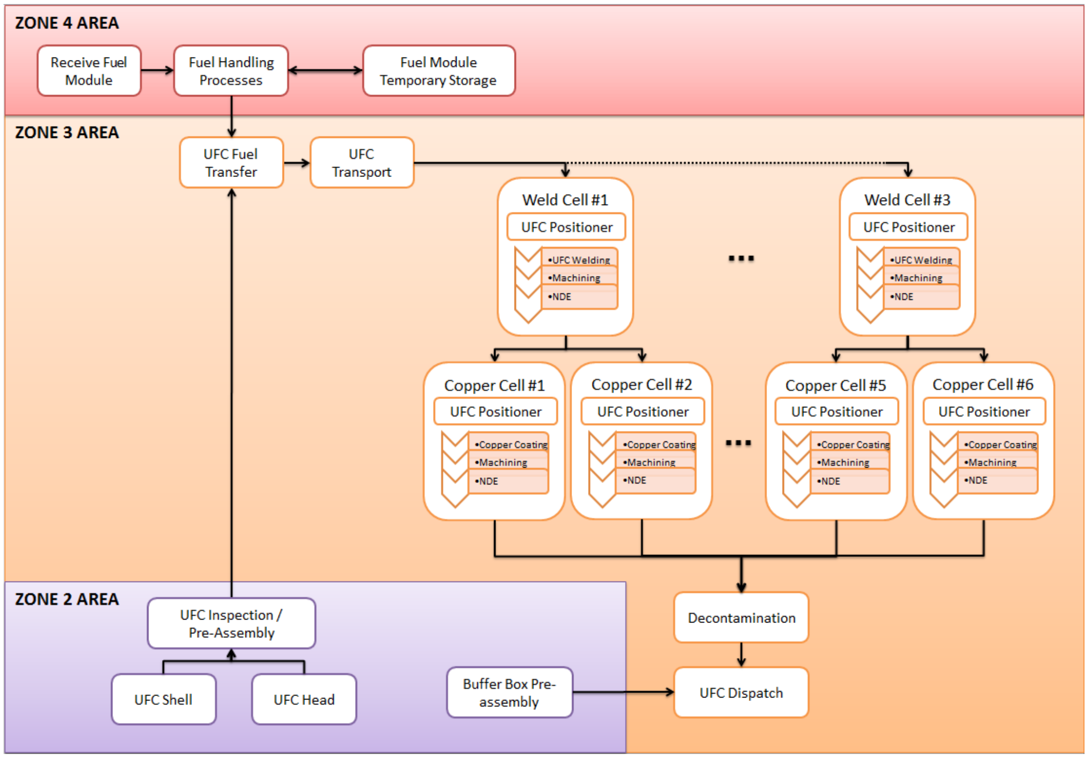


Figure 4: UFPP Concept Process Flow

Fuel arrives at the plant in a Used Fuel Transport Container (UFTP). Two parallel UFTP and fuel module handling cells are used to unload the modules from the UFTPs. The fuel modules are then transferred either to the Fuel Handling (FH) cells or to dry storage. Fuel modules designated to the FH cells will be distributed to one of three parallel operating FH cells. Within the FH cells, the fuel bundles are pushed through the used fuel module, inspected and loaded into the UFC.

Empty UFCs will be brought into the plant through conventional means in the Empty UFC Receiving & Handling area and pre-assembled into 'kits' for use in the downstream fuel loading and UFC processing cells. UFCs are loaded into a shielded flask inside the Intra-plant Transfer Hall. The flasks will be moved through the plant with an AGV system. With the UFC pre-assembled with the head installed, the UFC will be moved to the Fuel Loading cells. The UFC will be extracted from the flask and, presented to an actuated head removal station. Once the head is removed, the UFC will be picked up and transferred to an actuated position-adjustable worktable. The UFC will be filled with 48 fuel bundles and returned to the head removal station to re-install the head. Once installed, the UFC will be returned to the shielded flask where the AGV transfer system will move the UFC to one of the UFC weld processing cells.

Once at the UFC Weld Cell, the UFC is extracted again from the flask and transferred to a UFC Rotary Positioner. The UFC Rotary Positioner moves the UFC sequentially to each workstation within the weld cell. The five (5) UFC Weld Cell Workstations are: Pre-heat, Weld, Forced Air Cool, Machining and NDE Inspection. When the UFC head has undergone all assembly operations, the UFC is loaded back into the UFC flask and delivered via an AGV to one of the UFC Copper Application Cells.

The UFC is then extracted from the UFC Transfer Flask into the Copper Application Cell and transferred to a UFC Rotary Positioner similar to the UFC Weld Cell. The six (6) UFC Copper Application Cell Workstations are: Grit / Air Blast, Copper Spray, Machining, Anneal, Forced Air Cool and NDE Inspection. The UFC is then returned to the flask and brought to the decontamination and dispatch area of the UFPP.

At the Decontamination and Dispatch UFPP area, the UFC is extracted from the UFC Transfer Flask, swabbed for contamination, cleaned and transferred to the buffer box assembly area where the UFC is assembled in a bentonite buffer box and dispatched into the DGR.

The UFPP construction is planned as a ground level building to accommodate the material process flows with a small basement level to accommodate UFTP handling and UFC dispatch operations. The ground floor of the UFPP is approximately 88 x 254 metres including a total of 12 UFC processing cells.

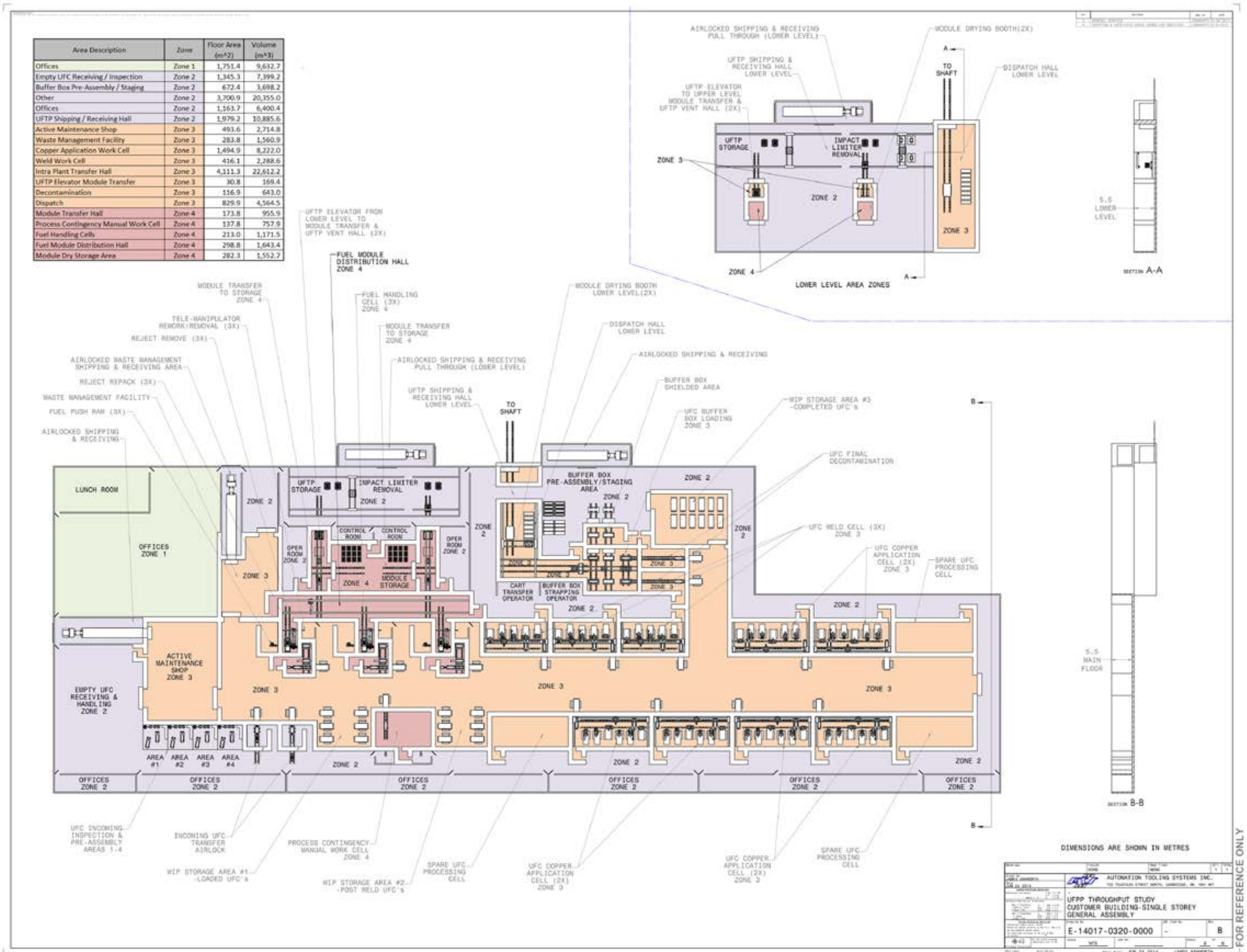
4.1 Radiation & Hot Cell Equipment Considerations:

The presence of radiation fields which are emitted from the used fuel within the UFC must be a consideration in the plant design as radiation effects on the equipment can have a substantial impact on the overall plant reliability.

Wherever possible within the plant, systems should be designed to minimize exposure levels and time exposed to radiation fields. In most cases the required operations do not require specialized tooling with motors and sensors to be in close proximity to the fuel. In these areas, shielding and external routing of drives can be implemented to minimize the effects of radiation. Where actuation and sensing is needed at the UFC, such as in the UFC processing cells, additional strategies to minimize exposure time should be employed. Relocating drives should be considered, not just for redundancy and recovery, but for accessibility for routine maintenance to maintain reasonable operating costs.

4.2 Throughput Evaluation

In order to provide a comprehensive review of the throughput capacity of the proposed UFPP concept design, the complex interaction between the different plant areas and parallel systems must be considered. For this purpose, a discrete event simulation was developed based upon the conceptual plant design, associated processing logic and steps times.



Area Description	Zone	Floor Area (m^2)	Volume (m^3)
Offices	Zone 1	1,751.4	9,632.7
Empty UFC Receiving / Inspection	Zone 2	1,345.3	7,399.2
Buffer Box Pre-Assembly / Staging	Zone 2	672.4	3,698.2
Other	Zone 2	3,700.9	20,355.0
Offices	Zone 2	1,163.7	6,400.4
UFTP Shipping / Receiving Hall	Zone 2	1,979.2	10,885.6
Active Maintenance Shop	Zone 3	493.6	2,714.8
Waste Management Facility	Zone 3	283.8	1,560.9
Copper Application Work Cell	Zone 3	1,494.9	8,222.0
Weld Work Cell	Zone 3	416.1	2,288.6
Intra Plant Transfer Hall	Zone 3	4,111.3	22,612.2
UFTP Elevator Module Transfer	Zone 3	30.8	169.4
Decontamination	Zone 3	116.9	643.0
Dispatch	Zone 3	829.9	4,564.5
Module Transfer Hall	Zone 4	173.8	955.9
Process Contingency Manual Work Cell	Zone 4	137.8	757.9
Fuel Handling Cells	Zone 4	213.0	1,171.5
Fuel Module Distribution Hall	Zone 4	298.8	1,643.4
Module Dry Storage Area	Zone 4	282.3	1,552.7

Figure 5: UFPP Layout by zone area

4.2.1 Input Parameters

The parameters considered in the development of the simulation include logical flow of operations and estimated automation handling & process times. Additionally, the model considered possible variability in certain parameters, which allows for variation in the model behaviour during consecutive runs by random seed input.

4.2.2 Analysis

The UFPP Simulation was performed using ProModel discrete event simulation software. The model was constructed to simulate the operation of the UFPP. The throughput model was constructed and run with different scenarios to evaluate throughput capability of the concept UFPP design.

4.2.3 Results and Discussion

One of the primary objectives of the study was to establish a UFPP system concept that will be capable of producing a net throughput of 12 UFCs per day. Baseline simulation results have shown that a batch of 12 UFC can be produced within 12.7 hrs with no downtime considered and within the expected operating time of 16.1 hours considering moderate levels of equipment downtime (80% availability).

From the baseline alternative simulation, it has been shown that the time associated with the key UFC processing steps has a dramatic impact on the plant production capacity. Further development and optimization of the key UFC processing steps will be essential for plant optimization. The summary of results can be found in the **Table** below.

Table: Summary of Baseline Alternative Scenario Results

Scenario	Average Batch Time (hours)
Baseline	12.7
Baseline: Alternative 1: Aggressive Automation Times	12.3
Baseline: Low Downtime (10% Down Time)	13.4
Baseline: Medium Downtime (30% Down Time)	16.1
Baseline: High Downtime (50% Down Time)	22.3

The overall UFPP plant concept presented herein has been shown to provide the necessary modularity and redundancy needed to maintain production rates over a planned 30+ year operational window. The modularity of the plant concept allows for adaptation to the change in production technologies and times by the addition or removal of UFC production cells.

5. Conclusions

The CANDU fuel specific UFC provides an opportunity for improvement with respect to system redundancy and handling practices in a UFPP. Given these opportunities, the concept plant design for the smaller UFC employs a modular approach having multiple and independent work cells to achieve the throughput targets. A throughput target of 12 UFCs net per day was found to be achievable with the baseline UFPP concept design with modest availability scenarios

With a view to providing a flexible and adaptive plant design, the proposed UFPP with a modular work cell approach allows for handling of off nominal scenarios such as rework or machine downtime with minimal impact to the plant throughput. Furthermore, the modular approach readily allows for expansion capability. The benefit in such flexibility will be especially important given the long planned operational period of the UFPP where changes in processing techniques and technologies are inevitable.

6. References

[1] SNC Lavalin. “NWMO APM Conceptual Design & Cost Estimate” 020606-6100-REPT-0001, Toronto, Ontario, Canada, 2011