Deliverable 5: Project Design and Cost Estimate

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Abstract

Our team (Group 18) has been tasked with designing and building a device meant to retrieve a metal sample from a tube in a CANDU reactor. This sample will then be sent to a lab to test the integrity of the tube. This report delineated the project's design process, “Ideate”. The design of our machine was finalized. The team also defined the building parameters and costs of our 3 prototypes, which will be built and presented in the following weeks. The full cost breakdown of the project was evaluated, and the next tasks were assigned to each member of the group, considering their capabilities and their availability. Testing for each prototype was also discussed. The project is now ready to move into the “Prototype” phase.

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1. Introduction

This report goes over the comprehensive plan for designing and creating the project prototypes to address all project requirements and customers' needs by the end of the semester. It provides details on the design, prototype processes, testing methods, and cost estimations. Additionally, the report provides a task schedule and estimated duration of each task along with the responsibilities of each team member. Furthermore, it addresses potential risks and ideas that may mitigate them. An estimated budget is also provided alongside a list of required materials and their purpose to ensure the team has the resources to carry out all project tasks efficiently. The goal is to design prototypes and carry out tests, validating each test to arrive at a high-quality product.

2. Project Goals and Scope

2.1 Purpose of This Deliverable

This deliverable will outline a clear plan for developing the project's three prototypes and the final design. It also will lay out the timeline, task responsibilities, and budget to ensure each of the prototypes is completed efficiently, from the initial proof of concept to the fully functional final version. This deliverable will also help us track the team's progress, distribute resources effectively, and manage risks while ensuring that the testing criteria are met and that the project stays on course.

2.2 Key Considerations

2.2.1 Physical Dimensions & Weight

- Length: ~4.57 m (15 ft) ± 0.15 m (0.5 ft) for full reach inside the tube.
- Diameter: ≤ 0.10 m (100 mm) to ensure fit within the tube.
- Weight: ≤ 6.80 kg (15 lbs) for ease of handling.
- Portability: Must break down into sections ≤ 1m for transport in tight spaces.

2.2.2 Sample Collection Requirements

- Precision: Must collect 30 - 80 mg of metal sample, ideally 55 mg ± 15 mg.
- Collection Method: Automated or semi-automated with an Arduino-controlled weight sensor for accuracy.
- Time Limit: The collection process should take ≤ 3 minutes per sample.

2.2.3 Sample Handling & Storage

- Sealed Storage: The sample must be contained without direct operator contact.
- Basic Storage: No radiation shielding is required, only secure containment.

2.2.4 Durability & Reliability

- Operational Life: Should withstand at least 100 extractions without failure.
- Materials: Reinforced 3D-printed materials and inexpensive durable metals.

- Failsafe Design:
    - Tethered to a remote handling system for retrieval in case of failure.
    - A secondary activation method or manual override is used for recovery.

2.2.5 Power & Electronics

- Energy Efficiency: Minimal power use, with an Arduino-based control system preferred.
- Avoid high-powered motors or complex electronics to stay within budget.

2.2.6 Budget Constraints

- Maximum cost: ≤ CAD 100.
- Use cost-effective materials, 3D printing, and small-scale electronics.

2.2.7 Constraints (Absolute Limits)

- Max weight: ≤ 10 kg (to remain manageable in low-mobility environments).
- Max size when deployed: ≤ 17 ft (5.18 m) in length, 100 mm in diameter.
- Operational Conditions: Standard temperature and pressure (STP)—no extreme heat, pressure, or radiation considerations.

3. Design Framework and Plan

3.1 Overview of Finalized Design

- The design implements a "cheese grater" that is rotated about the tube's axis with a motor to scrape off small amounts of metal (Figure 2). This grater is operated on a hinge; it extends out from the tube via centripetal force (Figure 3). The grater rotates for 10-15 revolutions and stops to let the debris settle on the load cell (Figure 2), which measures the mass of the collected debris and displays the mass on the laptop screen (Figure 1). This cycle is repeated until the measured mass matches the target mass of 55mg. Then, the motor's rotation is automatically stopped by the Arduino.

- The static portion and the rotating portion of the machine are held together by a hollow slip ring.

- The machine also implements a telescoping feature, which can reduce the length of the overall machine down to 8ft, making it more portable (Figure 1).

Figure 1

Final Detailed Sketch of the Mechanism, Section A

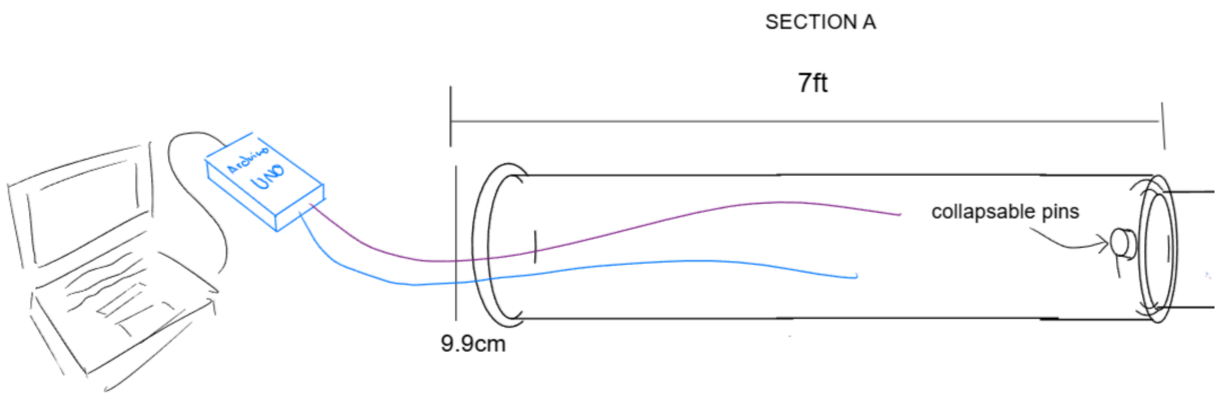


Figure 2

Final Sketch of the Mechanism, Sections B and C

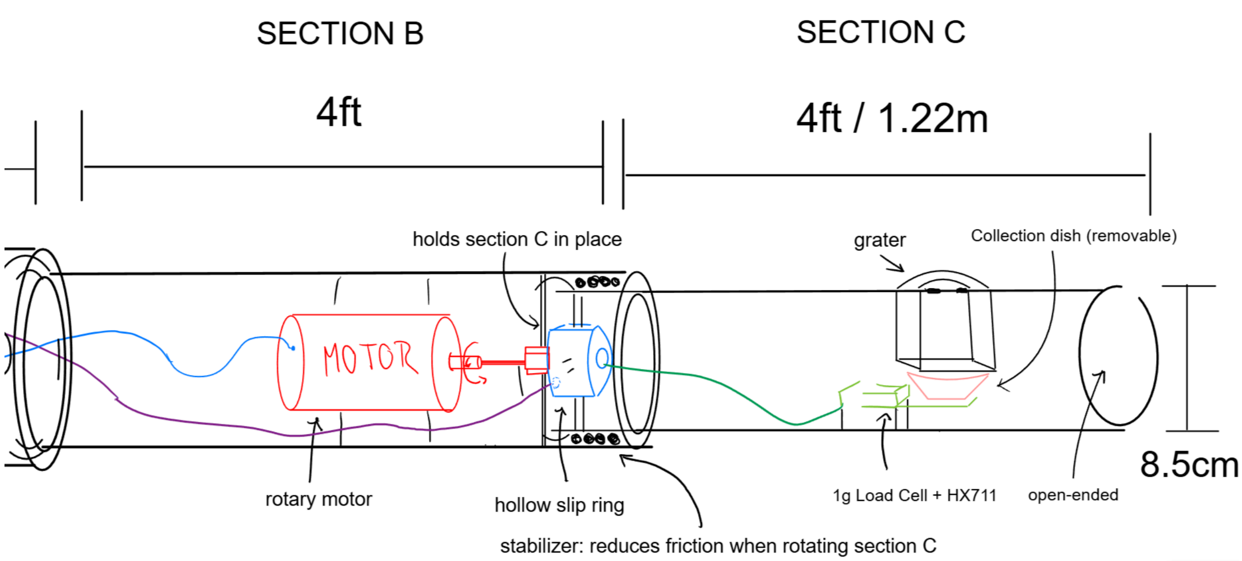


Figure 3

Rough Sketch of the Grater in the Open and Closed Position

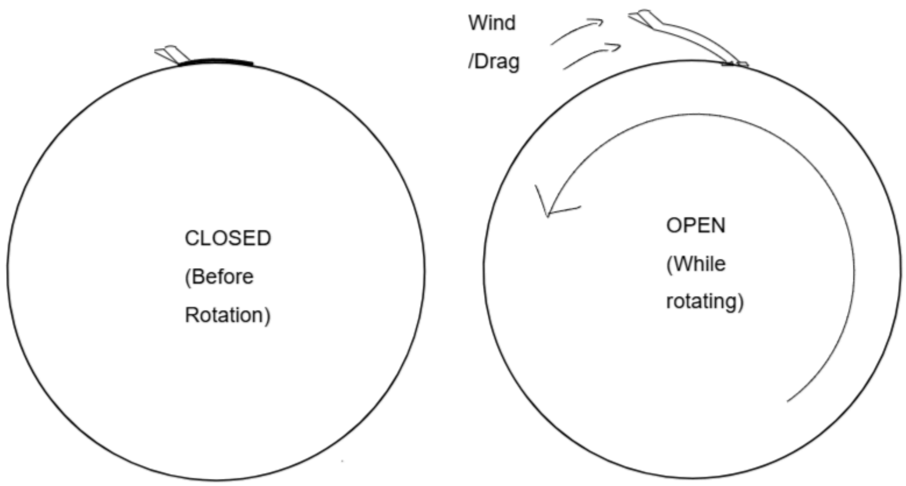


Figure 4

Alternate view of the Grater in the Open and Closed Position

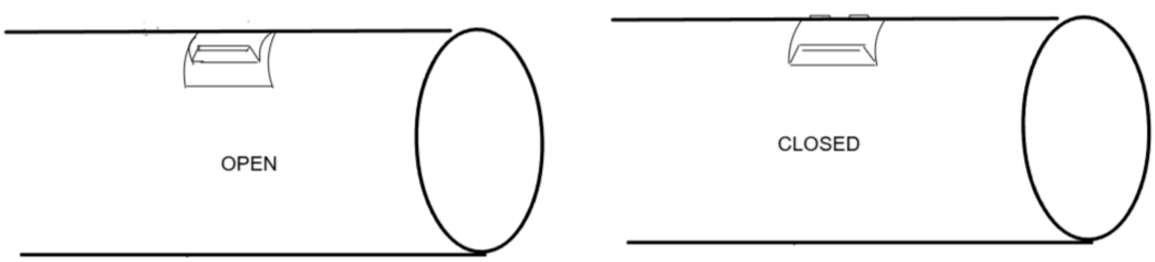
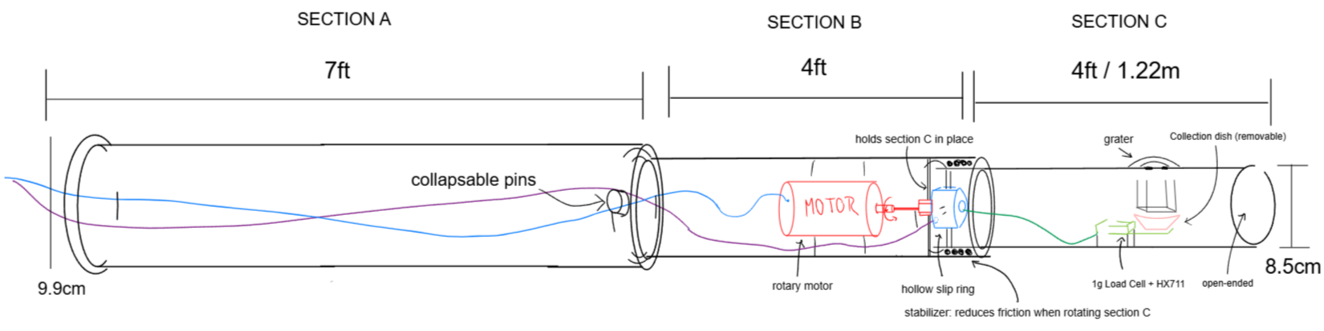


Figure 5

A complete, zoomed-out view of the Machine



3.2 Selection of Materials and Components

Tools:

- Wire stripper
- Wire cutter
- Pliers
- Pins

Mechanical components:

- PVC Pipe (for the outer shell of the machine)
- Acrylic material (for stabilizer and miscellaneous components)
- Steel sheet
- MDF board
- Steel pins/screws

Electrical components:

- Wires (~25 ft)
- 12V Motor

- Encoder for motor
- Hollow slip ring
- HX711 Sensor and Load Cell
- Arduino UNO
- Laptop

3.3 Design Constraints and Factors

- **Motor and Slip Ring Connection:**
  Modifications are required to properly connect the motor to the hollow slip ring.
- **Wiring:**
  Ensure that the wires connecting the load cell and the weight sensor can reach the Arduino without snapping or becoming entangled, even as Section C spins.
- **Grater Blade Stability and Durability:**
  Since the grater blade is engaged by both centripetal and lift forces, it must be strong enough to resist the opposing forces from the spinning section and the friction produced by scraping.
- **Motor Encoder Compatibility:**
  The motor encoder must be appropriately sized and compatible with both the motor and the hollow slip ring. It should rotate in sync with these components and accurately track the motor's revolutions.

4. Prototyping Plan

4.1 Prototype 1: Initial Concept Model

- Prototype Concept: It will test the feasibility of the grater blade. It looks to test the functionality of our blade to make sure there are no critical conceptual errors in our design. This prototype will include all the PVC piping.
- Materials:
  - PVC pipes
  - Collection tray (acrylic or similar plastic)
  - Steel (or similar metal) sheets for the grater blade
- Purpose: Simple and low-cost (manual) version of the device designed to test functionality, and to be aware of its suitability. It will be made using affordable or already

available materials to identify potential issues early on and fix any problems before moving on to more advanced prototypes.
Testing of the integrity of PVC pipes, as well as the blade's strength.

4.2 Prototype 2: Key Subsystem Development

- Prototype Concept: This prototype will focus more on the specific development and testing of one specific aspect of the project. This prototype ensures that the core functionality works as it should before including everything in the full main design. This prototype will be more refined than the first, with better materials to get a better result. It will focus on the rotary motor, and it will test its strength, speed, and precision. It will also test the electronic systems of the project.
- Materials:
  - Steel (or similar metal) sheets for the grater blade
  - HX711 Weight Sensor and Load Cell
  - PVC pipes
  - Hollow Slip Ring
  - Motor
  - Encoder
  - Wires
- Purpose: The purpose of this prototype is the verification of the critical components of the design and their functionality before moving into the final phases. By focusing on one specific part of the device, we can run tests, refine, and ensure that the design is feasible and reliable. This prototype will test the load cells, the rotary device, and the hollow slip ring.

4.3 Prototype 3: Complete Functional Model

- Prototype Concept: This is the final and complete version after all implementation has been added. It has all the components integrated into an operational model which resembles the final product. At this point in the project, the design should be as complete and close to the aspired product as possible, and it should already be refined, thoroughly tested, and functional.
- Materials:
  - Motor
  - Steel (or similar metal) sheets for the grater blade

        - Hollow slip ring
        - Wires
        - Encoder
        - Collection tray (acrylic or similar plastic)
        - HX711 Weight Sensor and Load Cell
        - PVC pipes
    - Purpose: To test the entire system under real-world conditions and confirm that all components work together as they should. It allows for overall performance evaluation, identification of any last-minute fixes/changes, and any final enhancements before submission. This is the final prototype which will represent our design which was brought to reality, hopefully ensuring that it has met all requirements and functionality.

5. Project Timeline and Task Distribution

5.1 Task Breakdown and Team Roles

Currently, the project tasks are allocated as follows:

• **Sam:** Oversees the electrical systems.

• **Sam, Deba:** Coding and debugging the control program for the prototype.

• **Sam, Nick, Deba:** Work on the CAD design of the prototype.

• **Ahmed:** Responsible for acquiring and preparing the tube for assembly, as well as sourcing any other required materials.

• **Louis:** Tracks the team's completed work, milestones, and overall progress.

• **Louis, Nick, and Sam:** Collaborate on calculations to address theoretical challenges.

★ Note that this task list may be adjusted to ensure efficiency.

5.2 Project Milestones and Deadlines

- Deliverable Deadlines:
    - Deliverable E - Project Plan and Cost Estimate (2/23/2025)
        - Finalize the project design for prototyping
        - Generate a cost estimate per prototype and for the entire project

- Formulate an action plan and deadline for the construction and adjustments of prototypes.

- Deliverable F - Prototype I and Customer Feedback (3/2/2025)
    - First prototype centered around the electrical system should be properly built and tested by the end of 2/28/2025
    - Any kinks with the prototype should be aptly addressed and an action plan should be generated for the following prototypes by 3/2/2025
- Deliverable G - Prototype II and Customer Feedback (3/9/2025)
    - The second prototype focused on the structural integrity and mechanical systems should be built and tested by the end of 3/7/2025
    - The structural and mechanical designs of the prototype should be perfected and ready to move on to the third and final prototype, it should also be tested for compatibility with the prototype
- Deliverable H - Prototype III and Customer Feedback (3/23/2025)
    - The third and final prototype needs to be tested for functionality, at this point in the development process only small adjustments should be made to either the code or certain small parts related to the electrical or mechanical systems.
- Deliverable I - Design Day Presentation (3/26/2025)
- Deliverable J Project Presentations
- Deliverable K - User and Product Manual (4/4/2025)

5.3 Risk Management and Contingency Plans

- The motor, hollow slip ring, and encoder may present compatibility problems which may result in many returns and repurchases to find the perfect compatibility between the three.
- The hollow slip ring and the weight sensor and load cells also present a risk, the latter must properly connect to the hollow slip ring for proper weight calculation by the Arduino.
- The “grater” blade is inspired by a hatch and thus runs the risk of snapping or deforming. To minimize this risk, the blade’s design will greatly focus on its structural integrity; materials, width-to-height ratio, and angle of approach to the area of operation.

6. Budget Estimation and Cost Breakdown

6.1 Bill of Materials (BOM) and Estimated Costs

- Refer to the BOM Excel document.
  - [Deliverable E - Bill of Materials (BOM)]

6.2 Required Equipment and Software

- Wire Strippers
- Voltage and Resistance Measurement Devices
- Wire Cutters
- Pliers
- Pins
- Laptop with Arduino IDE Software
  - Relevant libraries for additional special components

7. Testing and Validation Approach

7.1 Test Objectives and Success Criteria

- Prototype 1: Proof of Concept
  - Test 1: Basic functionality tests; ensuring the prototype demonstrates core concept(s).
  - Test 2: Stability/Durability; ensures structural integrity, modularity, and that the structure holds up while scraping (manual scraping).
  - Test 3: Feasibility; will verify whether the design can be further developed or not. The "grater" will be tested to ensure the hatchet won't deform and the scraping mechanism in sound.
- Prototype 2: Key Subsystem Development
  - Test 1: Load Cells; Ensure proper communication with Arduino board, and correct code, as well as correct measurements and displays.
  - Test 2: Rotary Device; Ensure the device is durable enough to maintain structural integrity and not snap.
  - Test 3: Hollow Slip Ring; Ensure it is compatible with all other parts of the device.
- Prototype 3: Full Functional Model
  - Test 1: Precision of collection; refine the mechanism to ensure maximum precision when collecting debris.

    - Test 2: Precision of rotary motor revolutions; ensure that the motor's rotation always ends with the "grater" facing up, within a small margin of error.
    - Test 3: Friction does not cause any significant wear and tear in any part of the system.

7.2 Conditions for Test Completion

- Prototype 1: Proof of Concept
    - Test 1: Passing initial functionality tests without failure (Major).
    - Test 2: Stays stable while scraping for a given duration of time for a set amount of trials.
    - Test 3: "Grater" does not deform.
- Prototype 2: Key Subsystem Development
    - Test 1: System successfully reads and displays correct measurements with different loads without occurring errors.
    - Test 2: The rotary device withstands pressure during tests without breaking or showing significant signs of wearing.
    - Test 3: The Hollow slip ring integrates properly without interference or failure in connectivity.
- Prototype 3: Full Functional Model
    - Test 1: Collection falls within +-5 mg of 55 mg consistently.
    - Test 2: The motor is consistently stopping at the correct position with little to no variance over multiple test cycles (<+-5 degrees of error).
    - Test 3: After dozens of trials, the stabilizer, the blade, and the joints of the machine show negligible signs of wear and tear.

7.3 Execution Strategy and Expected Outcomes

- Prototype 1: Proof of Concept
    - Test 1: Basic Functionality; confirmation for prototype functionality. Expected outcome: Core concept(s) work, allowing for development.
    - Test 2: Material Choice; decide whether the chosen materials are practical. Expected outcome: Materials provide sufficient durability and functionality for the initial testing. No significant wear and tear across various tests.
    - Test 3: Feasibility Test; determine if the design can be refined and further expanded. Expected outcome: Identification of any necessary adjustments for further developments.
- Prototype 2: Key Subsystem Development
    - Test 1: Connect and test with Arduino board for correct data transmission. Expected outcome: The system successfully reads and displays accurate values showing proper sensor function.
    - Test 2: Apply force and operate under different conditions to assess its durability. Expected outcome: The rotary device stays intact, proving sufficient and respectable structural integrity for future tests.
    - Test 3: Integrate with the system and check for proper electrical and mechanical connections. Expected outcome: The hollow slip ring transfers signals correctly without running into complications with other components.

- Prototype 3: Full Functional Model
  - Test 1: Run tests using differing code and voltage to adjust the speed of the “grater”. Ideal “grater” speed will consistently collect around 5mg of debris before every mass check of the sensor, ensuring that collection is predictable consistently. Expected outcome: Initially, the mass of the debris is variable (30mg to 80mg), but after calibration, it falls within the target mass.
  - Test 2: Run the motor through several cycles and analyze its stopping accuracy. Expected outcome: The motor consistently stops with the “grater” facing up, keeping little error margin within the given range.
  - Test 3: Run collection (Test 2) and check the wear and tear after every trial. Note down any differences. Cross-reference trials with pictures to find small changes. Expected outcome: The wear and tear is minimal.

8. Project Monitoring and Adjustments

8.1 Adjustments in Workload and Task Allocation

Although the tasks and responsibilities of each team member have been established, changes may be made to accommodate the evolving needs of the project. The quality of each project deliverable will be evaluated and team members will be tasked based on their strengths. This ensures that each team member can add the most value. Additionally, team meetings are held weekly so that members can voice their difficulties, this will improve coordination and efficiency of the team.

8.2 Conflict Resolution and Team Coordination

Communication between team members has been clear so far and this is expected to continue. The group has fostered a friendly atmosphere where group members are comfortable sharing their opinions. If there are any conflicts among group members, they can be addressed during team meetings where everyone works together to find common ground and resolve any disagreements quickly and effectively before they escalate. Should there be any conflicts that the team cannot resolve, we will introduce a third party, such as a T.A., to help guide us. Additionally, aside from team meetings, there are several other means of communication between team members so that everyone is reachable. This maintains good team coordination.

9. Final Conclusions and Additional Notes

9.2 Conclusions

Some minor design specifications are yet to be consolidated, but the project is fully functional and coherent. Before physical prototyping, the team will design a CAD model to ensure there are no inherent flaws in the design. Our team is confident in the design and ready to move into the next stages of development.

9.2 Additional Notes

1. If the collected tube is magnetic, a magnet can facilitate the collection of the debris (placing a weak magnet on the collection tray to “trap” the metal).

2. The only piece that can get stuck in the tube is the “grater” blade if it snaps. To retrieve it, we can add a strong magnet on the tip of the system so the blade adheres to it when we take the machine out (fail safety). The feasibility of this solution is also dependent on the magnetic properties of the tube we are collecting from.