Client Needs Identification and Problem Statement

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Abstract

Canadian Nuclear Laboratories (CNL) is a private sector company contracted to manage and operate nuclear research facilities on behalf of Atomic Energy of Canada Limited (AECL), a federal crown corporation. The company owns and operates several facilities across Canada, where work is conducted in various fields, including reactor fleet sustainability, hydrogen and tritium technologies, radiobiology, and national security and infrastructure.

Chalk River Laboratories, located in the Upper Ottawa Valley, is one of the primary facilities where teams focus on these research areas. The task assigned to this group comes from one such team called **EMED**, which specializes in the design, construction, and commissioning of specialized equipment and tooling for low-access, high-dose environments. The task involves developing a device to extract a sample of metal from the inside of a fuel channel that supplies Uranium fuel to a nuclear reactor.

This task is being approached through the design process, which includes the stages of empathize, define, ideate, test, and prototype. The primary objective of this report was to complete the first and second stages, which are the **empathizing and defining stages**. The empathizing stage began by identifying the needs of the project by considering the concerns expressed by the client, and by benchmarking with similar devices available in the market. These needs were then categorized based on their importance. The defining stage involved formulating

a problem statement that incorporates the final list of needs of the project. This problem statement will serve as the foundation for future work on the project.

Introduction

The **Canadian Deuterium Uranium (CANDU) nuclear reactor** is designed to use natural uranium fuel and heavy water as both a coolant and moderator. This design enables on-power refueling, making it a safe and reliable reactor that can generate approximately 600 megawatts of electricity per unit. (*How A nuclear reactor works* 2021)

In a CANDU reactor, uranium fuel (usually in the form of uranium hydride) is supplied through fuel channels that operate under high temperature and pressure. The presence of hydrogen ions under these conditions can lead to **hydrogen embrittlement**, a process in which hydrogen ions diffuse into the metal lattice, weakening the surface. This weakened surface can then crack, potentially causing uranium leaks, which are particularly hazardous due to the radioactive nature of the fuel. (*What is hydrogen embrittlement? - causes, effects and prevention*)

To prevent such incidents, standards set by the **Canadian Nuclear Safety Commission (CNSC)** must be followed in the design, fabrication, inspection, and testing of fuel channels. The testing process includes obtaining a metal sample from the interior of the tube and analyzing its hydrogen content. If the hydrogen content exceeds a certain threshold, the tube must be replaced. Otherwise, the tube is deemed suitable for continued use.

For the sample extraction, a technician must use a tool to obtain between 30 and 80 grams of metal from inside the tube without damaging its surface, as this could compromise the integrity of the tube. The challenge for the group is to develop a tool that meets these requirements, while also addressing needs (Refer to the respective sections for more details) identified by the client (EMED team), and through the benchmarking process.

Needs of The Client

The following table (Table 1) provides a detailed list of the needs identified by the EMED team, organized according to their level of importance. Explanations for the significance of each need are also included to justify the prioritization.

Table 1: Needs identified by the client.

Need	Level of Importance	Explanation of Importance
The device must be capable of extracting a metal sample from the interior of a tube that is 4.572 meters long, with a diameter of 101.6 millimeters and a wall thickness of 4.1 millimeters.	Critical.	The device must be of the right width and height to be able to easily fit inside the tube. Additionally, it must be able to at least reach the middle of the tube (2.286 m), as it is at this point that the sample is extracted.
The device must be fail-safe, such that it can be removed from the tube in the event of failure.	Critical	All components of the device must be removable from the tube in the event of a failure. Any part left inside the tube would prevent its use for transporting fuel to the reactor. Additionally, dismantling the tube to retrieve the device would be very costly.
The device must be usable in	Critical	The tube may be oriented

a tube that is oriented vertically as well as horizontally.		horizontally or vertically. Therefore, the device must be able to safely retrieve the sample in both cases.
The sample retrieved from the tube must be stored in a suitable container, and must not come in direct contact with the device operator.	Critical	The metal sample obtained from the tube is radioactive, making it hazardous to any individual who comes into direct contact with it.
Power sources required for the functioning of the device must be specified in the design.	Critical	The EMED team must be aware of the device's need for electricity to operate. This is essential so they can ensure an adequate electricity supply is available at the location of the tube. However, it is important to note that the device may not require electricity to function, and in this case, this need would not be a matter of concern.
The device must be reusable.	Critical	One of our clients main missions is to restore and protect the environment, this means that they want all devices manufactured to be

		environmentally friendly and reusable. Along with that, the client stated it would not be feasible to require a new device after one or only a handful of uses with the expensive technology required for development.
The device must have some method of providing feedback to the user to confirm the status of the collection process.	Highly desirable	After inserting the device into the tube, it may be necessary for the operator to determine the specific location of the device inside the tube in order to know when to collect the sample. Additionally, the operator should be able to recognize when the sample collection process has been completed, indicating when to remove the device from the tube. While this mechanism is not essential, its absence would mean that the collection process might need to be repeated multiple times if the correct quantity of the sample is not obtained.

The device must include a method for adjusting the sample retrieval process to ensure that the sample obtained weighs between 30 and 80 grams.	Highly desirable	It is essential to obtain the correct quantity of the sample. Acquiring too much of the sample could cause damage and weaken the structure, while obtaining too little would prevent an accurate test from being conducted. However, while using an inbuilt mechanism to set the amount of sample is an efficient way of obtaining the sample, it may not be necessary as this can be achieved by simply using a collection container that can collect only up to 80 grams of the sample.
All parts of the device must have the capability to be broken down to man-portable sizes.	Highly desirable	Breaking the tool into smaller, man-portable modules allows easier handling in confined spaces, such as airlocks, stairwells, or restricted-access areas. Modular designs also enable pre-assembly and testing in safe zones, minimizing

		on-site assembly time and reducing radiation exposure. Additionally, maintenance and decontamination are easier, as individual modules can be repaired, replaced or cleaned without dismantling the entire tool. Moreover, if contamination occurs, only the affected module requires storage or disposal, minimizing radioactive waste and preserving other usable components.
The device must be able to pass through a tube that may not be straight.	Slightly desirable.	Although the tubes are generally straight, they tend to sag under the weight and pressure of the fuel. Therefore, it would be beneficial to have a device capable of functioning in both straight and bent tubes.

Other Points of Importance

- The tube is clean, dry, and operates at room temperature and atmospheric pressure.

- The metal sample is only a few microns thick, and the internal surface of the tube does not need to have a smooth finish after the sample is extracted.
- Existing designs should not be considered during the design process. The group is expected to generate entirely new ideas.
- If the metal sample is being scraped, the potential for sparks emitted from the friction between the device's blade and the surface must be taken into account.
- Cameras can be used to track the device's location inside the pipe. Additionally, the radioactive nature of the metal does not need to be factored into the design.
- The device can be made out of Steel or Aluminium.

User Benchmarking

It is important to note that metal scraping tools, such as the Kinectrics CWEST and the tool developed by Canadian Nuclear Laboratories, are already available on the market. Examining these tools to identify any weaknesses or limitations could provide valuable insights and highlight areas for improvement, which could then be addressed in the development of this project.

However, there is limited information available online about these products, making it impossible to conduct a thorough benchmarking process. Additionally, the client (the EMED team) has specifically requested that this group not consider any pre-existing products during the design process.

Problem Statement

The EMED team at Canadian Nuclear Laboratories needs a portable, fail-safe device capable of extracting a metal sample from the interior of a tube in both vertical and horizontal orientations. The device must be capable of passing through potentially warped tubes, store the sample safely without exposing the sample to the operator, provide operator feedback, and collect only between

30 and 80 grams of the sample. Additionally, the device must be reusable, and compact enough to be broken down into man-portable sizes.

Conclusion

This group was tasked with developing a device to extract a metal sample from the interior of a fuel channel that supplies uranium fuel to a nuclear reactor. This process will follow the engineering design methodology, consisting of the stages: empathize, define, ideate, test, and prototype.

The focus of this report was to complete the empathize and define stages of the design process. The empathize stage was successfully concluded by identifying and prioritizing the client's needs. This step also involved providing a clear rationale behind the prioritization, ensuring a comprehensive understanding of the client's requirements.

However, the benchmarking process could not be conducted due to limited information and a request from the client to refrain from carrying out any benchmarking.

In the define stage, the team formulated a problem statement that includes all the needs expressed by the client (EMED team at CNL). This clear problem definition will serve as the foundation for the subsequent stages of the project.

Work Cited

How a nuclear reactor works. Canadian Nuclear Association. (2021, May 26). https://cna.ca/reactors-and-smrs/how-a-nuclear-reactorworks/

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